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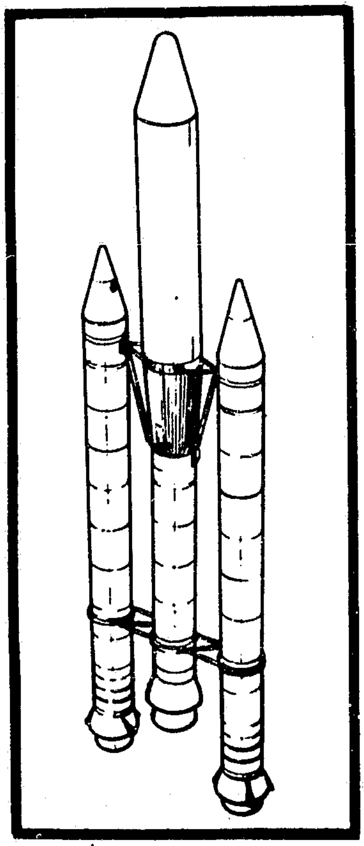
SRB-X

SHUTTLE DERIVED VEHICLE ANALYSIS
SOLID BOOSTER UNMANNED LAUNCH VEHICLE
CONCEPT DEFINITION STUDY



FINAL REPORT
VOLUME II

TECHNICAL REPORT

D180-27351-2
FEBRUARY 1983

NASA/MSFC
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BOEING

SRB-X

SHUTTLE DERIVED VEHICLE ANALYSIS
SOLID BOOSTER UNMANNED LAUNCH VEHICLE
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Volume II

TECHNICAL REPORT

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by

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Seattle, Washington 98124

FOREWORD

The Shuttle Derived Vehicle Analysis Solid Booster Unmanned Launch Vehicle Concept Definition Study, hereafter referred to as the SRB-X study, NASA Contract NAS8-34722, was managed by NASA Marshall Space Flight Center (MSFC) and performed by the Upper Stage and Launch Vehicle Preliminary Design organization of Boeing Aerospace Company (BAC) in Seattle, Washington. Major support was provided by Thiokol/Wasatch Division and NASA Kennedy Space Center (KSC) Design Engineering Office. The NASA Contracting Officer's Representative (COR) was James E. Hughes.

This final report is organized into the following documents:

- Volume I: Executive Summary
- Volume II: Technical Report

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Payload shrouds.	Lockheed Missile and Space Company
Titan SRM	Chemical System Division

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GLOSSARY

ASE	airborne support equipment
AT	access tower
ATP	authorization to proceed
BAC	Boeing Aerospace Company
CCAFS	Cape Canaveral Air Force Station
CER	cost-estimating relationship
CG	center of gravity
C/O	checkout
COR	Contracting Officer's Representative
DDT&E	design, development, test, and evaluation
DOD	Department of Defense
EEC	extendable exit cone
ET	external tank
ETR	Eastern Test Range
FBR	forward bearing reaction
FFU	first flight unit
fps	feet per second
FSS	fixed service structure
FWC	filament-wound case
FY	fiscal year
GEO	geosynchronous Earth orbit
GLOW	gross liftoff weight
GSE	ground support equipment
GVTA	ground vehicle test article

HB	high bay
HEUS	high energy upper stage
HHC	hammerhead crane
HPM	high-performance motor
IEA	integrated electronics assembly
IOC	initial operating capability
IUS	inertial upper stage
KSC	Kennedy Space Center
LC	launch complex
LEO	low Earth orbit
LETF	launch equipment test facility
LM	launch mount
LPS	launch processing system
MDM	multiplexer demultiplexer
MEOP	maximum expected operating pressure
MLP	mobile launcher platform
MSFC	Marshall Space Flight Center
MST	mobile service tower
NASA	National Aeronautics and Space Administration
OMS	orbital maneuvering subsystem
OPF	orbiter processing facility
OTV	orbital transfer vehicle
PCM	Parametric Cost Model
PCR	payload changeout room
PPR	payload preparation room
POST	Program to Optimize Simulated Trajectories
PSF	processing and storage facility
psf	pounds per square foot
psia	pounds per square inch absolute

RCS	reaction control system
RF	radiofrequency
ROM	rough order of magnitude
R&PM	research and program management
RSS	rotating service structure
SDV	shuttle-derived vehicle
SE&I	system engineering and integration
SRB	solid rocket booster
SRM	solid rocket motor
STA	structural test article
STS	space transportation system
TVC	thrust vector control
T/W	thrust to weight
UFS	ultimate factor of safety
VAB	vehicle assembly building
VAFB	Vandenburg Air Force Base
VPF	vehicle processing facility
WTR	Western Test Range

1.0 INTRODUCTION

This volume documents the technical effort associated with the selection and definition of the recommended SRB-X concept. Included are discussions concerning the trades leading to the selected concept, the analysis that established the concept's basic subsystem characteristics, selected configuration description and performance capabilities, launch site operations and facility needs, development schedule, cost characteristics, risk assessment, and a cursory comparison with other launch systems.

1.1 BACKGROUND

The SRB-X study was initiated by NASA in response to preliminary investigations that suggested future launch requirements could best be satisfied by a mixed fleet of manned and unmanned launch vehicles. Manned requirements are expected to be met by the space shuttle, at least to the turn of the century, but requirements for the unmanned vehicle are not specific at this time. The following, however, represent potential uses or benefits that indicate, when viewed collectively, that an unmanned vehicle could be a valuable addition to the space transportation system (STS). Such a vehicle could—

a. Provide shuttle contingency or backup in the event of an out-of-service orbiter, major accident, or failure to achieve acceptable turnaround time.
b. Deliver payloads that exceed the size and mass constraints imposed by the shuttle.
c. Free the shuttle for missions unique to its capabilities, thus extending the life of the orbiter fleet.
d. Supplement the shuttle flight rate in the event launch needs increase appreciably.
e. Deliver cargo considered hazardous or presenting additional risk to the shuttle.

The SRB-X is one of several shuttle-derived vehicle (SDV) concepts being considered for the unmanned launch vehicle role. The distinguishing feature of the concept is that, to the greatest extent possible, primary propulsion would use the space shuttle's solid rocket motors (SRM), boosters, or derivatives rather than the LO_2/LH_2 main propulsion system.

1.2 OBJECTIVES

The overall study objective was to provide a preliminary concept definition for NASA to compare with other candidates. The specific objectives were to—

a. Conduct trade and sensitivity analyses to determine the most promising concept.

b. Determine performance capabilities, mission and operational characteristics, and facility requirements.

c. Develop cost and schedule characteristics for the selected concept.

1.3 GUIDELINES AND ASSUMPTIONS

Principal guidelines and assumptions used during the study were—

a. Consideration of variations in STS solid rocket motor in terms of case material, number of segments, propellant, and nozzle design.

b. Consideration of other types of solids and liquid stages for intermediate and upper stages.

c. Interchangeability of payload and vehicle elements with STS as a desirable goal.

d. Launch from either Kennedy Space Center (KSC) or Vandenburg Air Force Base (VAFB).

e. An original initial operating capability (IOC) of 1987, subsequently revised to 1990.

f. Payload capabilities revised to--

 1. Low Earth orbit (LEO)—comparable to STS (greater than or equal to 60,000 lb)
 2. Polar—STS mission 4 (greater than or equal to 32,000 lb)
 3. Geosynchronous Earth orbit (GEO)—existing and planned upper stages available by IOC (greater than or equal to 15,000 lb with advanced cryogenics)

IOC was revised to 1990 to reflect NASA redirection of the earliest date for a new start—1986 rather than 1984. Accordingly, payload requirements were adjusted to reflect needs in the 1990's.

1.4 SCOPE OF ACTIVITY

The study consisted of 10 months of technical effort and 2 months of documentation. Emphasis during the first quarter was on investigating a wide range of concepts and conducting several screenings to obtain the selected concept. Visits were made to Thiokol/Wasatch Division, which is responsible for STS solid rocket booster (SRB) manufacturing, and to VAFB, KSC, and Cape Canaveral Air Force Station (CCAFS) launch facilities. During the second quarter, a preliminary definition of the selected concept was performed, followed by final system definition with emphasis on programmatics in the third quarter. Table 1.4-1 summarizes the scope of activity.

Table 1.4-1. *Scope of Activities*

SRB-X-404

- ATP 11/25/81
- COMPLETION 11/25/82

FIRST QUARTER

- DATA EXCHANGE WITH SUPPORTING CONTRACTORS AND GOVERNMENT AGENCIES
- TRENDS IN CRITICAL SUBSYSTEMS
- PRELIMINARY PERFORMANCE
- ETR AND WTR INSPECTION
- FACILITY REQUIREMENTS
- CONCEPT SCREENINGS (3)

SECOND QUARTER

- CONFIGURATION CHARACTERIZATION
- PRELIMINARY SUBSYSTEM DEFINITION
- PERFORMANCE IMPROVEMENT POTENTIAL
- OPERATIONAL CHARACTERISTICS
- COMPLETE FACILITY REQUIREMENTS
- PRELIMINARY COST AND SCHEDULE

THIRD QUARTER

- FINAL CONFIGURATION DEFINITION
- FINAL PERFORMANCE CAPABILITIES
- GROUND OPERATIONS
- TEST PROGRAM
- FINAL COST AND SCHEDULES

FOURTH QUARTER

- DOCUMENTATION

2.0 SUMMARY

Over 1100 vehicle concepts were examined during the selection process for the recommended SRB-X concept. Several screening cycles reduced the number of candidates when relative payload capability and impact on launch complex were considered primary evaluation criteria. Final configuration selection emphasized the ability to satisfy expected payload requirements for the 1990's, with 15,000 lb to GEO being the most demanding.

2.1 FINDINGS

Principal findings, including the selected configuration, are summarized in figure 2.1-1.

Configuration. The launch system is a three-stage vehicle that relies heavily on technology available from existing programs. Stage 1 consists of two reusable four-segment STS SRB's. Filament wound cases (FWC) are baselined for performance reasons; however, no significant impact on recurring cost is expected. Stage 2 also uses a solid rocket motor consisting of two of the STS FWC segments but with a new grain design and optimized nozzle. Stage 3 is a modified version of the Titan core stage II. Key features include a 50% increase in storable propellant loading and a higher expansion ratio nozzle. Avionics for vehicle guidance and control are located in a control module located immediately above stage 3. Due to load considerations, both stage 3 and the control module are enclosed within an interstage during the first 185 sec of flight. Any existing or currently planned upper stage can be accommodated for missions above LEO. The payload shroud allows accommodation of shuttle-sized payloads.

Performance. As a three-stage vehicle, over 60,000 lb can be placed in a 100-nmi, 28.5-deg orbit; 49,000 lb into 100-nmi, 90-deg orbit; and 18,000 lb into GEO transfer. Use of an advanced cryogenic stage, such as the high-energy upper stage (HEUS), would allow 16,000 lb placed in GEO. Acceleration levels are compatible with payloads designed for shuttle delivery.

Facility Requirements. Facilities available at KSC and VAFB are adequate for system processing and vehicle assembly and launch. Most of the facilities are the same as for the shuttle; however, a limited amount of modification is necessary. Principal

VEHICLE HT.
WTR 195 FT
ETR 219 FT

FACILITIES
STS AT ETR AND WTR

PAYLOAD CAPABILITY (LBS)
LEO 60,700
POLAR 49,000
GEO 12,100 (MIN.)
16,000 POSSIBLE

GLOW 3,408,000 LBS

DEV TIME 4.5 YEARS

DEV COST $750M

COST/FLIGHT $100M

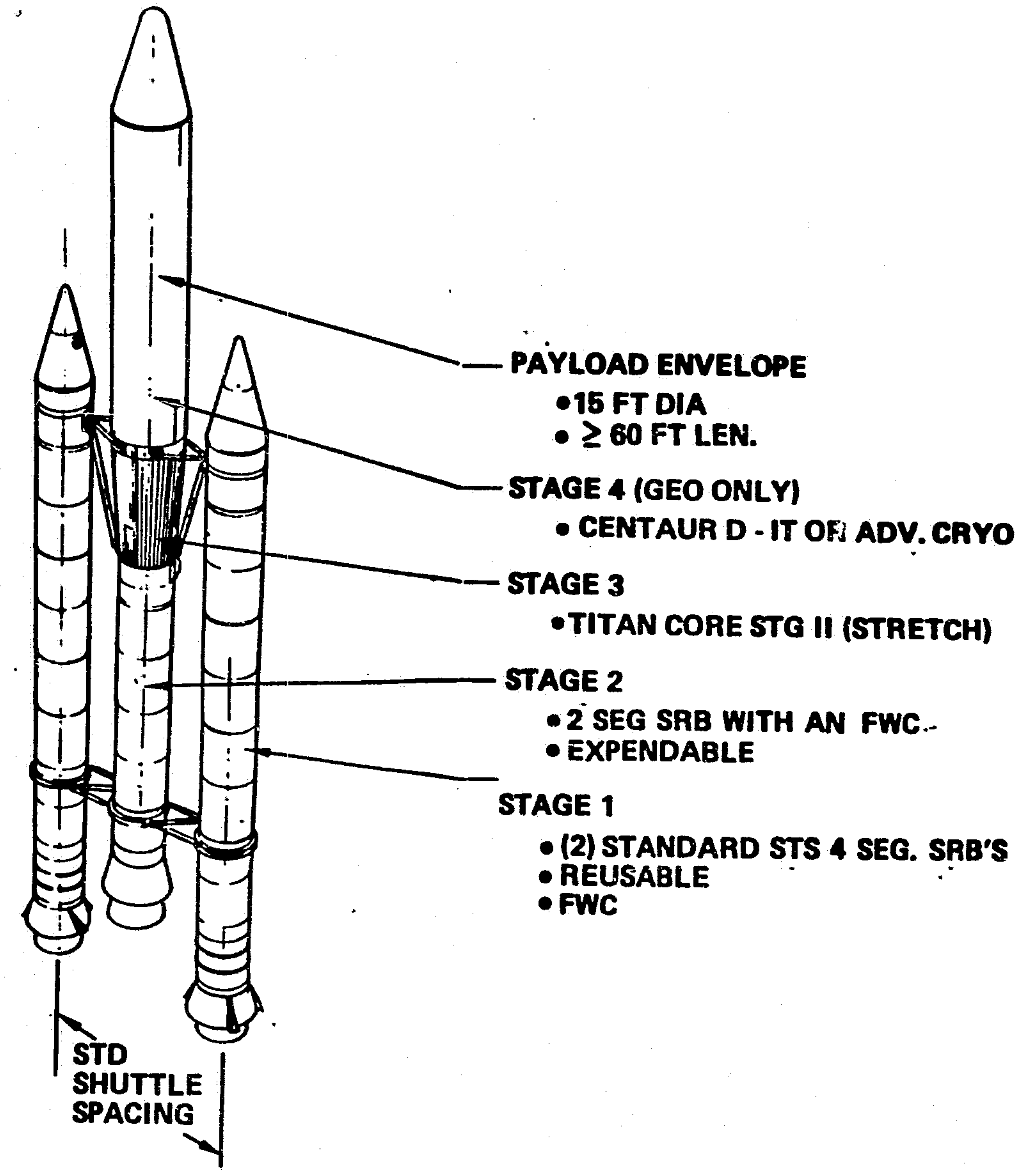

Figure 2.1-1. Study Findings

modifications at both sites include provisions for access platforms and umbilicals necessary for vehicle core elements; and at KSC, a new pad crane is also required.

Implementation Plan. The first launch of the SRB-X is projected within 4-1/2 years after phase C/D go-ahead. This schedule assumes no preimplementation effort and a conservative test program. Key tests include five test firings of the new stage 2 SRM and integrated vehicle tests to verify primary loadpaths, coupled dynamics, and facility interfaces. Most of the facility equipment can be installed on a noninterference basis relative to the shuttle. The lone exception is at KSC pad 39B, where installation could best be done with a 6-month shutdown. Theoretically, however, pad 39A can handle all but 15% (two or three) of expected launches at that time, barring any accident.

Cost. Development costs associated with the program are estimated at approximately $745 million in 1982 dollars. The vehicle contribution is $630 million and facility modifications (at KSC and VAFB), $115 million. Cost per flight for the three-stage vehicle, based on six flights per year, is estimated at $100 million.

Risk. The SRB-X concept is judged to be a low-risk program, primarily because of the extensive use of existing systems, components, and facilities. No new technology development areas were identified. The most significant risk is that of the availability of the Titan core stage II, used as the third stage for SRB-X. Titan production is presently scheduled to end 3 years prior to SRB-X IOC. Reopening of the production line has been estimated at $30 to $40 million. An alternative to this stage is an MX-type first stage; however, the LEO payload would be decreased by nearly 7000 lb.

Comparison With Non-SDV's. When compared with non-SDV's, such as growth Atlas, Titan, or Ariane, the SRB-X was found to have considerable advantages in payload capability, delivery cost per pound of payload, and operational flexibility. Principal disadvantages are higher development cost and potentially longer development time.

Conclusion. An SRB-X unmanned launch vehicle, as illustrated in figure 2.1-2, relying heavily on STS SRM and SRB technology was found to have performance, operational, and cost characteristics that would make it an effective supplement to the Nation's space transportation system, should the need exist.

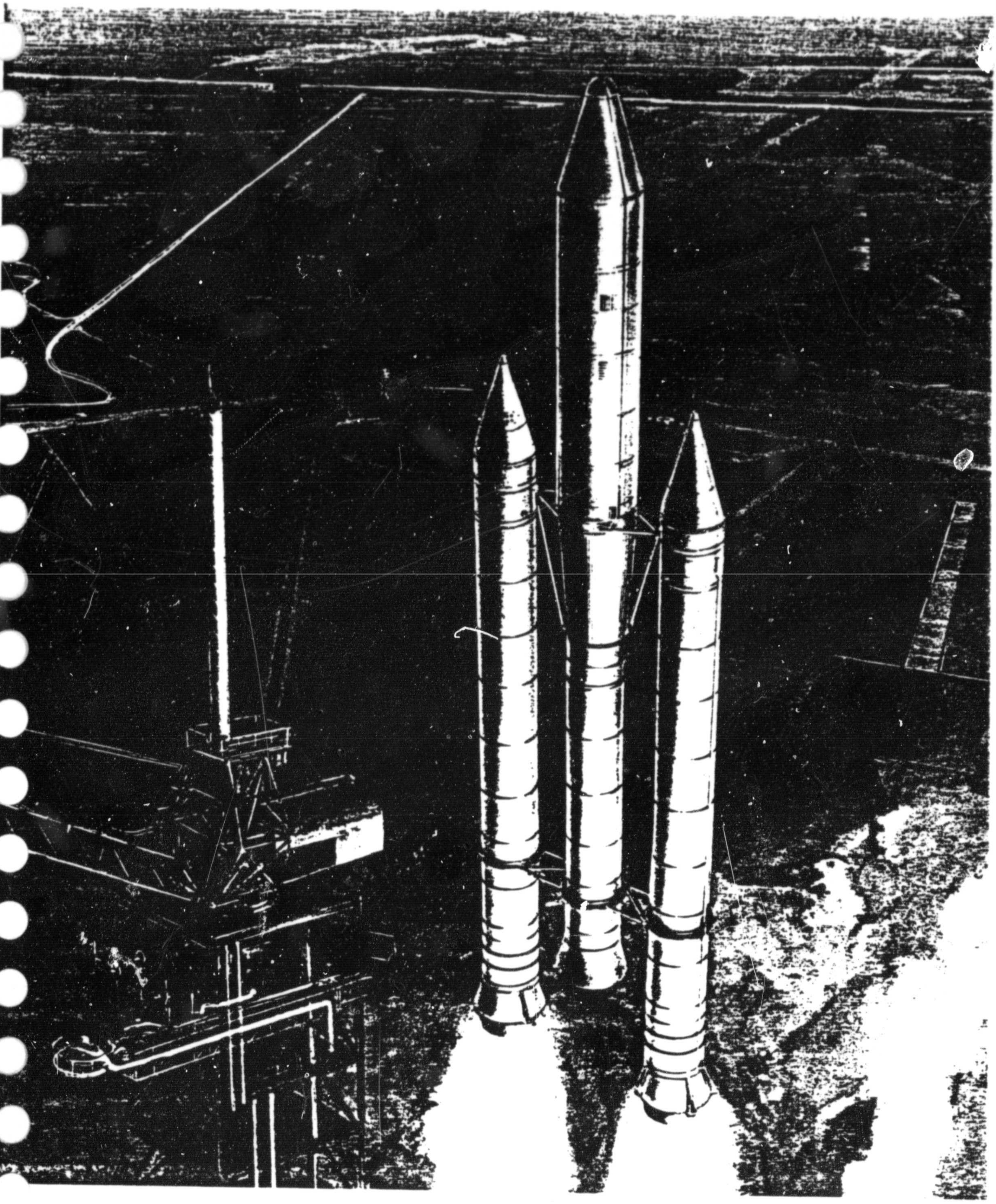

Figure 2.1-2. SRB-X Concept

2.2 RECOMMENDATIONS

Recommendations from this study are not exclusive to SRB-X alone. They also deal with the general topic of SDV's that could supplement the shuttle. The rationale for this approach is that concepts such as SRB-X and those defined in references 1 and 2 have reached a level of maturity to allow an overall assessment and formulation of a launch vehicle plan. Accordingly, the following steps are recommended.

a. Compare the various SDV concepts against foreseeable mixed fleet scenarios. Several scenarios are appropriate because of the uncertainty that exists in shuttle launch requirements and operational capability. The expected output would be a recommended concept for each scenario investigated.

b. Address the critical elements that must be resolved for each selected SDV-scenario combination. Such action would allow rapid response to the possibility of an urgent mixed-fleet requirement in the foreseeable future. Conceivably, this action may include some predevelopment effort.

An extensive launch vehicle data base exists. Action should be taken to convert this information into implementation plans for future needs.

3.0 CONCEPT AND CONFIGURATION TRADES

This section describes the various concepts considered and the analyses associated with selecting a preferred concept. Because a very large number of configuration options were possible, a rather complete discussion is presented to indicate how the preferred concept was selected.

3.1 CONCEPT OPTIONS

The development of candidate SRB-X concepts took into consideration the wide range of payload requirements to be satisfied at the beginning of the study as well as the large number of existing stages that could be utilized. To satisfy payload needs, three basic vehicle classes (designated A, B, and C) were identified. Differences between the classes are in the numbers of boosters used at liftoff: class A uses a single booster; class B, two boosters burning in parallel; and class C, three boosters burning in parallel. Payload targets for each class are shown in figure 3.1-1. Three- and four-stage vehicles were investigated for each payload destination.

The stage options considered focused heavily on the use of the STS SRM, particularly for first- and second-stage application. The segmented or component nature of this SRM, as indicated in figure 3.1-2, provided the opportunity to use various combinations to form SRM's, ranging from one to five segments and consequently offering a wide range of options. Options available for third and fourth stages also included derivatives of the STS SRM as well as other existing SRM's and systems using storable and cryogenic propellant.

The class A vehicle concepts identified are shown in table 3.1-1. A total of 432 three- and four-stage options were identified. A given concept is formulated by combining one of the types of systems listed under each stage until a three- or four-stage vehicle is available. Examples of several options are indicated as well as the coding method used for identification in the performance model. Also to be noted is the addition of strapons for this class of vehicle as a means to provide additional payload capability. The only stage option indicated that was not currently available or in procurement as a basic system or a derivative thereof was the widebody Centaur. Not included at the time of concept identification was the HEUS; however, it was considered prior to the selection of the recommended configuration.

The class B vehicle options are shown in table 3.1-2. Because two boosters form the first stage, a wider range of options exists for the first and second stages relative to class A. Options for stages 3 and 4 are the same as for class A. A total of 432 vehicle

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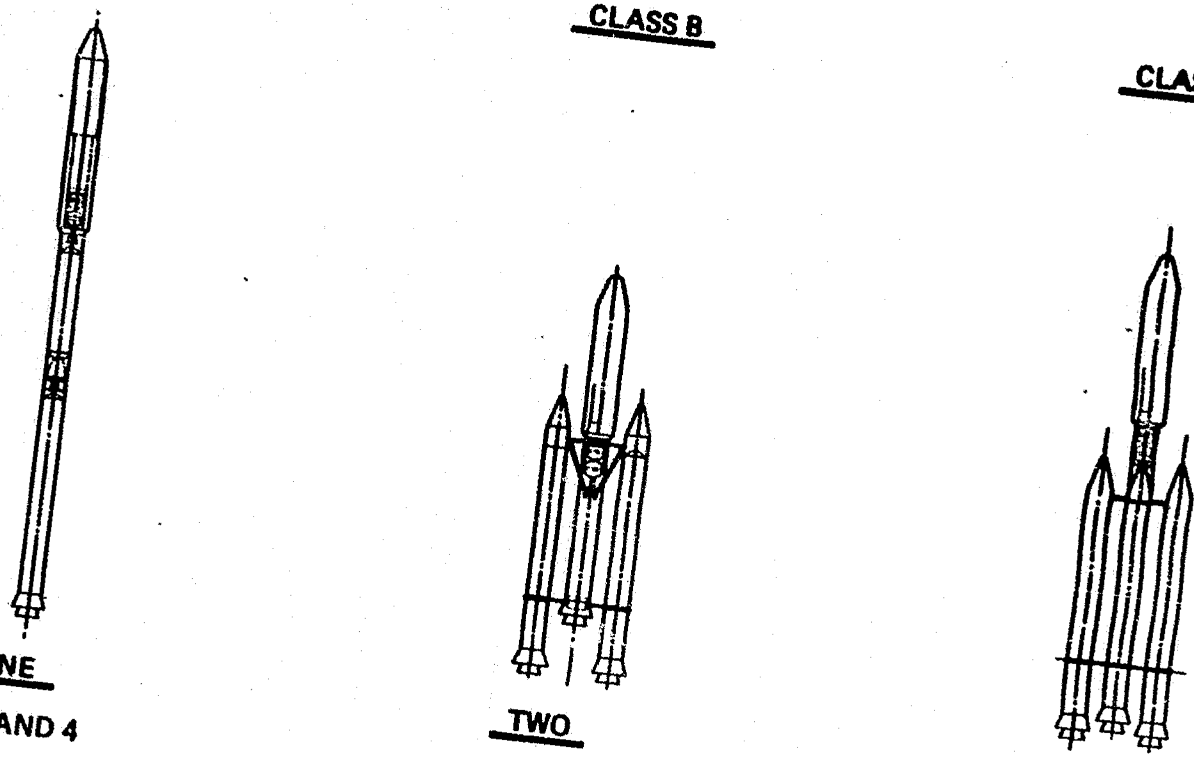

	CLASS A	CLASS B	CLASS C
BOOSTER STAGES	ONE	TWO	THREE
VEHICLE STAGES	3 AND 4	3 AND 4	3 AND 4
PAYLOAD TARGETS (SOW) KLBS			
LEO	35,000	65,000	95,000
POLAR	25,000	45,000	65,000
GEO	7,000	12,000	17,000

Figure 3.1-1. Configuration and Concept Vehicle Trades

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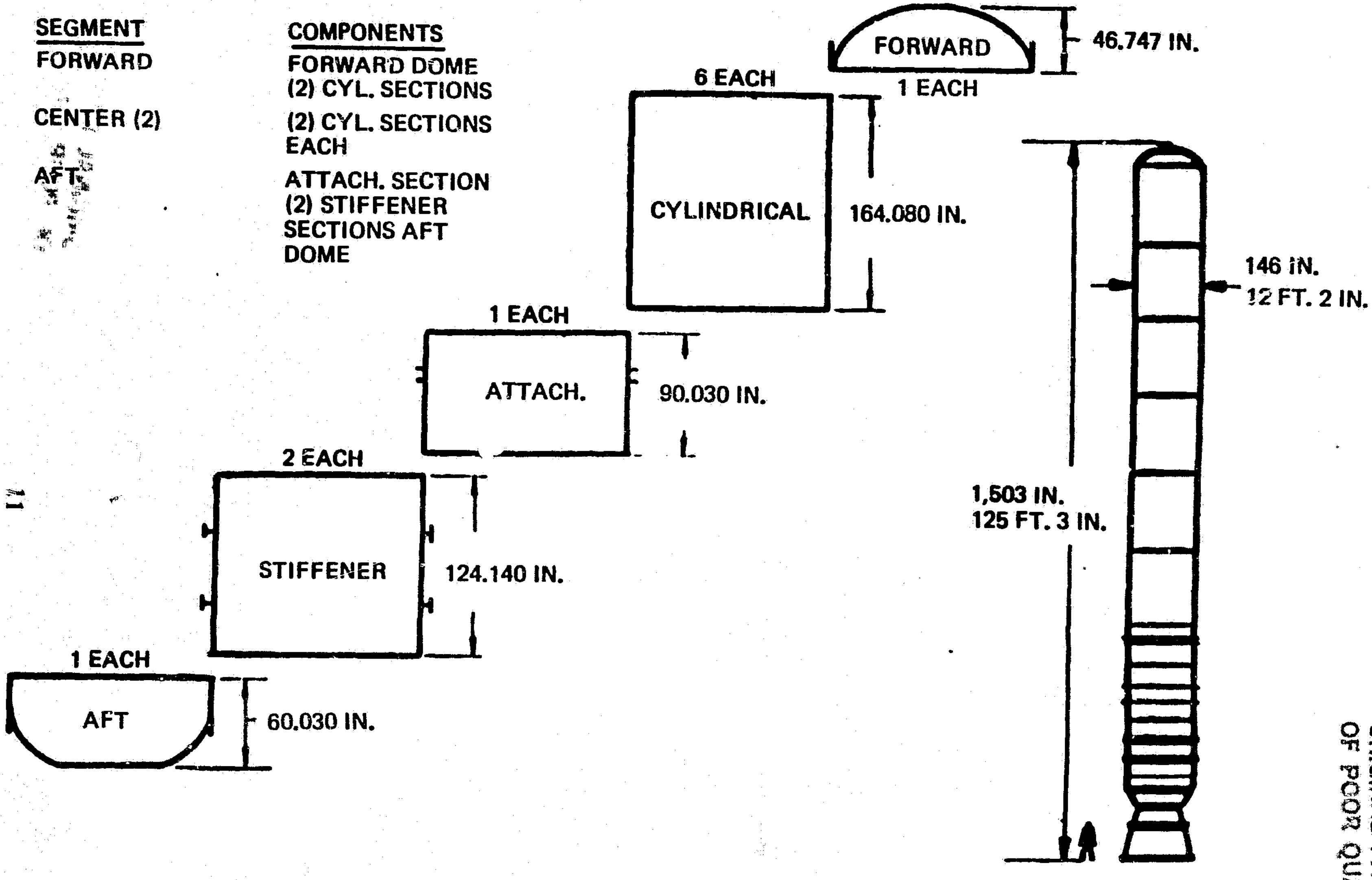
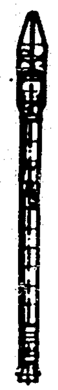


Figure 3.1-2. STS-SRM Steel Case Components

Table 3.1-1. SRB-X Class A Options

• 432 COMBINATIONS

STRAP-ONS	1ST STAGE OPTIONS	2ND STAGE OPTIONS	3RD STAGE OPTIONS	4TH STAGE OPTIONS
1. 2 X 1 SEGMENT SRB	1. 4-SEGMENT SRB	1. 1-SEGMENT SRB	1. CENTAUR	1. TRANSTAGE
2. TITAN 3 5 SEG S/O		2. 2-SEGMENT SRB	2. WIDEBODY CENTAUR	2. IUS
3. 3 X 1 SEG SRB			3. TITAN 2ND STAGE	3. CENTAUR
4. 4 X 1 SEG SRB			4. ADV SLM 1ST (S2) ▷1	4. WIDEBODY CENTAUR
5. TITAN 7 SEG S/O			5. ADV LLM 1ST (S1) ▷2	5. ADV LLM 2ND (S3) ▷2
6. DELTA CASTORS (14)			6. 1 SEG SRB	



CONFIGURATION/STAGE OPTION COMPUTATION CODE

ZERO
1ST
2ND
3RD
4TH

TYPICAL 3 STAGE: 0 – 1 – 1 – 1 – 0

4 SEG
1 SEG
CENTAUR

TYPICAL 4 STAGE: 0 – 1 – 2 – 3 – 3

4 SEG
2 SEG
TITAN 2ND
CENTAUR

▷1 TRIDENT DERIVED

▷2 MX DERIVED

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Table 3.1-2. SRB-X Class B Options

• 432 COMBINATIONS

1ST STAGE OPTIONS	2ND STAGE OPTIONS	3RD STAGE OPTIONS	4TH STAGE OPTIONS
1. 2 X 3-SEGMENT SRB	1. 2-SEGMENT SRB	1. CENTAUR	1. TRANSTAGE
2. 2 X 4-SEGMENT SRB	2. 3-SEGMENT SRB	2. WIDEBODY CENTAUR	2. IUS
3. 2 X 5-SEGMENT SRB	3. 4-SEGMENT SRB	3. TITAN 2ND STAGE	3. CENTAUR
	4. 5-SEGMENT SRB	4. ADV SLM 1ST (S2) [1]	4. WIDEBODY CENTAUR
		5. ADV LLM 1ST (S1) [2]	5. ADV LLM 2ND (S3) [2]
		6. 1-SEGMENT SRB	

[1] TRIDENT DERIVED

[2] MX DERIVED

TYPICAL 3 STAGE: 0 – 1 – 3 – 1 – 0

1: 2 X 3 SEG; 3: 4 SEG; 1: CENTAUR

TYPICAL 4 STAGE: 0 – 2 – 3 – 3 – 3

2: 2 X 4 SEG; 3: 4 SEG; 3: TITAN 2ND; 3: CENTAUR

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options were also possible for the class B vehicle. Class C vehicles considered are presented in table 3.1-3. A total of 216 options were identified.

3.2 SCREENING PROCESS OVERVIEW

The process of analyzing the large number of vehicle options and eliminating less desirable options involved three separate steps. An overview of this process is shown in table 3.2-1. Subsequent subsections will discuss each step in detail. The first screening step considered the total spectrum of concept options but was confined to using ideal delta V's. Only FWC's were considered because payload capability is a major criterion and it was felt that if a given concept could not satisfy the requirement with FWC, it certainly would fail with steel cases. Another major consideration was that of facility impact. A number of class A options involved strapons and class C options provided large payload capabilities, but many options within both classes were eliminated due to severe facility impacts. As a result, only 12 basic configurations were considered for the second screening.

During the second screening analysis, the decision was made to utilize three-stage vehicles for LEO and polar and four-stage vehicles only for GEO missions. Velocity requirements were adjusted as a result of preliminary POST runs. Vehicle performance was determined for both steel and FW cases. Primarily as a result of the steel case performance assessment, the number of configuration options was reduced to six.

The final screening of the first quarter was done using delta V's from POST runs related to each vehicle option and for each mission. The analysis also involved updated stage performance and weight characteristics.

3.3 FIRST SCREENING ANALYSES

The primary objective of the first screening was to reduce the number of options so a more thorough analysis could be performed on those remaining. The approach used to accomplish the objective was to develop preliminary system characteristics in terms of weight and propulsion data for each vehicle stage option and determine vehicle level differences that would result in the elimination of some options.

3.3.1 System Characterization

Preliminary weight estimates were established in terms of stage inerts, interstages, and payload shrouds. Propulsion characteristics defined included specific impulse (Isp), thrust, and propellant loading.

Table 3.1-3. SRB-X Class C Options

• 216 COMBINATIONS

1ST STAGE OPTIONS	2ND STAGE OPTIONS	3RD STAGE OPTIONS	4TH STAGE OPTIONS
1. 3 X 4-SEGMENT SRB	1. 3-SEGMENT SRB	1. CENTAUR	1. TRANSTAGE
2. 3 X 5-SEGMENT SRB	2. 4-SEGMENT SRB	2. WIDEBODY CENTAUR	2. IUS
	3. 5-SEGMENT SRB	3. TITAN 2ND STAGE	3. CENTAUR
		4. ADV LLM 1ST (S2)	4. WIDEBODY CENTAUR
		5. ADV LLM 1ST (S1)	5. ADV LLM 2ND (S3)
		6. 1-SEGMENT SRB	

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Table 3.2-1. Configuration Screening Process

FIRST SCREENING ⊳1	SECOND SCREENING ⊳2	THIRD SCREENING

• IDEAL DELTA V
• PRELIMINARY STAGE WEIGHTS AND PERFORMANCE
• FWC SRM
• ~ 1100 CONFIGURATIONS 3 AND 4 STAGE VEHICLES
• CRITERIA
  • LEO AND GEO PAYLOAD
  • G LEVEL
  • FACILITY IMPACT (QUALITATIVE)
	• IDEAL DELTA V WITH SELECTED ADJUSTMENT
	• PRELIMINARY STAGE WEIGHTS AND PERFORMANCE
	• FW AND STEEL CASE SRM
	• 12 BASIC 3 STAGE CONFIGURATIONS
	• CRITERIA
	  • 3 STAGE FOR LEO AND POLAR
	  • 4 STAGE FOR GEO
		• POST DELTA V'S
		• UPDATED STAGE WEIGHTS AND PERFORMANCE
		• FW AND STEEL SRM
		• 6 BASIC 3 STAGE CONFIGURATIONS PLUS 4TH STAGE FOR GEO
		• CRITERIA
		  • PAYLOAD
		  • FACILITY IMPACT
		  • STABILITY AND CONTROL
		  • DEVELOPMENT COST (PRELIMINARY)

⊳1 REPORTED IN 1ST QUARTER COORDINATION BRIEFING JANUARY 19, 1982

⊳2 REPORTED IN 1ST QUARTER PROGRESS TO DATE FEBRUARY 15, 1982

Characteristics associated with STS SRM derivates involving one through five segments are shown in table 3.3-1. It should be noted that the SRM's reflect use of FW rather than steel cases. This approach was used because the lower inert weight would give better vehicle performance; if a given concept could not satisfy performance targets with FWC, neither could it with steel. The longitudinal expansion (0.6 in) is the same as that used for the shuttle. Five- and three-segment motors reflect the same nozzle as the four-segment SRM used with the shuttle. One- and two-segment motors reflect nozzles restricted to 132-in diameter, as dictated by interstage constraints.

A complete listing of weight and propulsion characteristics for each type of stage considered, as well as weights for other vehicle elements, is presented for class A, B, and C vehicles, respectively, in tables 3.3-2, -3, and -4. It will be noted that differences have been indicated for many of the characteristics for a given SRM depending on the stage application. Interstage weights relate to the stage indicated and the stage immediately above it. The exception is on class B and C vehicles where the interstage between stages 1 and 2 has been included within the subsystem weights of stage 1. Shroud weights reflect the length of the stage involved as well as a percentage of the expected payload for the vehicle. A very preliminary estimate of unit cost is also included and supplemental cost data are provided in table 3.3-5.

3.3.2 Evaluation Factors

The primary factor used to screen candidate vehicle concepts was LEO and GEO payload capability. Key factors associated with the performance estimates are as follows:

a. LEO orbit with altitude of 100 nmi and inclination of 28.5 deg.

b. Staging orbit for GEO missions of 100 nmi.

c. Ideal delta V for all destinations.

   1. LEO: 30,000 fps.

   2. GEO: 44,000 fps.

d. Shroud separation immediately after second-stage separation.

e. Zero and/or first-stage burns initiated together.

f. Liftoff thrust-to-weight ratio based on maximum SRM thrust.

g. Burnout thrust-to-weight ratio based on average thrust.

Other factors, such as those that follow, were also used to evaluate and screen the vehicle concepts:

Table 3.3-1. *STS-SRM Derivative Characteristics*

SRB-X-35

- Data reflects FWC with 0.6 inch growth for 4 segment motor

Characteristic	5[1] Segments	4 Segments *	3[2] Segments *	2[3] Segments *	1[3] Segment	1[4] Segment
Stage Application	1,2	1,2	1,2	2,3	0,2,3	0
Thrust, Vac (lbf)	2,946,000	2,350,000	2,031,000	1,298,000	717,000	1,450,000
I_{sp}, VAC (sec)	267	267	267	277	285	277
Burn Time (sec)	125	126	111	126	126	60
Total Impulse (lbf-sec)	368×10^6	294×10^6	225×10^6	162×10^6	89.6×10^6	87×10^6
Propellant Wt (lbm)	1,379,000	1,107,000	835,000	586,000	314,000	314,000
Inert Weight (lbm) [1]	127,132	111,597	95,943	64,804	43,418	44,638
Total Motor Wt (lbm)	1,506,132	1,218,597	930,943	650,804	357,418	350,638
Motor Mass Frac	.916	.908	.878	.900	.878	.876

*DATA FROM THIOKOL

1. Nozzle throat sized for same average P_C as 4 segment
2. Same nozzle as 4 segment, burn-rate adjusted to match MEOP
3. Light, non-reuseable nozzle & higher expansion ratio
4. Nozzle change and enhanced burn rate

[1] Motor inert weights do not include TVC system

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Table 3.3-2. SRB-X Class A Stage Characteristics

APPLICATION	STAGE NAME	CODE NUMBER	WEIGHTS ▷ PROP	INERT	INTER STAGE	INERT EXPEND.	PERFORMANCE ▷ VAC THR	ISP	BURN TIME	EXP RATIO	THROAT AREA	UNIT COST	SHROUD WEIGHTS FIXED	PER LB P/L
STRAP-ONS	14 CASTOR	A 0 5	289940	49030	0	0	890400	229.9	50	10	0	14000000	0	0
	7SEG TITAN	A 0 6	592860	89910	0	0	1622750	270	124	10	0	18000003	0	0
	-NULL 0TH-	A 0 0	0	0	0	0	0		0.00001	0	0	0	0	0
	SRB 2X1 FB	A 0 1	628000	138480	0	0	2900000	277	60.0	13.6	2450.8	9000000	0	0
	TIT3 0TH	A 0 2	850000	167800	0	0	2354000	266	96.05	10.0	1832.2	15000000	0	0
	SRB 3X1 FB	A 0 3	942000	207720	0	0	4350000	277	60.0	13.6	3676.2	13500000	0	0
	SRB 4X1 FB	A 0 4	1256000	276960	0	0	5800000	277	60.0	13.6	4901.6	18000000	0	0
STAGE 1	SRB 1X4	A 1 1	1107000	146300	5000	0	2850000	267.2	125.6	7.72	1987.1	7000000	0	0
	SRB 1X4 S0	A 1 2	1107000	148700	5000	0	2850000	267.2	125.6	7.72	1987.1	7000000	0	0
STAGE 2	SRB 1X1	A 2 1	314000	52920	2500	0	717280	285.2	125	28.3	543.3	9000000	0	0
	SRB 1X2	A 2 2	586000	74500	2500	0	1298600	277	125	14.8	1034.9	11000000	0	0
STAGE 3	CENT D1-T	A 3 1	30000	4850	1500	275	30000	444	444	57	43.0	13000000	7434	.12
	CENT UB	A 3 2	45000	6640	1500	275	33000	448	611	57	43.0	21000000	8950	.10
	TIT34D 2ND	A 3 3	66380	7250	1500	50	100864	316	208	35.4	93.1	10000000	2350	.12
	S-2	A 3 4	38800	6200	1500	3000	170000	280	64	10.0	124.3	3000000	3270	.12
	S-1	A 3 5	96000	9000	1500	100	522400	283	52	10.0	1103	7000000	3410	.12
STAGE 4	SRB 1X1	A 3 6	314000	51120	1500	0	717280	285.2	125	28.3	543.3	9000000	4450	.24
	-NULL 4TH-	A 4 0	0	0	0	0	0		0.00001	0	0	0	0	0
	TIT3 TRAN	A 4 1	23100	4100	0	0	15700	302	444	30	40.0	10000000	0	0
	IUS 2STAGE	A 4 2	27400	4720	0	0	39700	298	247	70	36.0	30000000	0	0
	CENT D1-T	A 4 3	30000	4850	0	275	30000	444	444	57	43.0	13000000	0	0
	CENT UB	A 4 4	45000	6640	0	275	33000	448	611	57	43.0	21000000	0	0
	S-3	A 4 5	54000	4500	0	0	300000	304	55	10	300.0	2400000	0	0

▷ VALUES REFLECT TOTAL OF EACH ITEM (E.G. [2] 1-SEG SRB'S)

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Table 3.3-3. SRB-X Class B Stage Characteristics

APPLICATION	STAGE NAME	CODE NUMBER	WEIGHTS ▷ PROP	INERT & SUBSYS	INTER STAGE	INERT EXPEND.	PERFORMANCE ▷ VAC THR	ISP	BURN TIME	EXP RATIO	THROAT AREA	UNIT COST	SHROUD WEIGHTS FIXED	PER LB P/L
STAGE 1	-NULL 0TH-	B 0 0	0	0	0	0	0	0.00001	0	0	0	0	0	0
	SRB 2X3	B 1 1	1669700	271000	0	0	5900000	267.2	111	7.72	3974.2	11000000	0	0
	SRB 2X4	B 1 2	2214000	311400	0	0	5700000	267.2	125.6	7.72	4290.6	14000000	0	0
	SRB 2X5	B 1 3	2761140	345800	0	0	5400000	266.2	157.4	7.72	4556.8	17000000	0	0
STAGE 2	SRB 1X2	B 2 1	586000	80500	5000	0	1298600	277.0	125	14.8	1034.9	11000000	0	0
	SRB 1X3	B 2 2	834850	112000	5000	0	1542000	267.2	144	7.72	1987.1	13000000	0	0
	SRB 1X4	B 2 3	1107000	128100	5000	0	2353000	267.2	125.6	7.72	1987.1	15600000	0	0
	SRB 1X5	B 2 4	1380570	143800	5000	0	2335500	266.2	157.4	7.72	2278.4	17000000	0	0
STAGE 3	CENT D1-T	B 3 1	30000	4850	1500	275	30000	444	444	57	43.0	13000000	7435	.12
	CENT WB	B 3 2	45000	6640	1500	275	33000	448	611	57	43.0	21000000	8950	.10
	TIT34D 2ND	B 3 3	66380	7200	1500	50	100864	316	208	35.4	93.1	10000000	2350	.12
	S-2	B 3 4	38800	6200	1500	3000	170000	280	64	10.0	124.3	3000000	3270	.12
	S-1	B 3 5	96000	9000	1500	100	522400	283	52	10.0	1103	7000000	3410	.12
	SRB 1X1	B 3 6	314000	51120	2500	0	717280	285.2	125	28.3	543.3	9000000	4450	.24
STAGE 4	-NULL 4TH-	B 4 0	0	0	0	0	0	0.00001	0	0	0	0	0	0
	TIT3 TRAN	B 4 1	23100	4100	0	0	15700	302	444	30	40.0	10000000	0	0
	IUS 2STAGE	B 4 2	27400	4720	0	0	39700	298	247	70	36	30000000	0	0
	CENT D1-T	B 4 3	30000	4850	0	275	30000	444	444	57	43.0	13000000	0	0
	CENT WB	B 4 4	45000	6640	0	275	33000	448	611	57	43.0	21000000	0	0
	S-3	B 4 5	54000	4500	0	0	300000	304	55	10	300.0	2400000	0	0

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▷ VALUES REFLECT TOTAL OF EACH ITEM (E.G. [2] 1-SEG SRB'S)

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Table 3.3-4. SRB-X Class C Stage Characteristics

APPLICATION	STAGE NAME	CODE NUMBER	WEIGHTS ▷ PROP	INERT & SUBSYS	INTER STAGE	INERT EXPEND.	PERFORMANCE ▷ VAC THR	ISP	BURN TIME	EXP RATIO	THROAT AREA	UNIT COST	SHROUD WEIGHTS FIXED	PER LB P/L
STAGE 1	-NULL 0TH-	C 0 0	0	0	0	0	0		0.00001	0	0	0	0	0
	SRB 3X4	C 1 1	3321000	467100	0	0	8550000	267.2	125.4	7.72	5961.4	21000000	0	0
	SRB 3X5	C 1 2	4141720	518700	0	0	8100000	266.2	157.4	7.72	6835.2	25500000	0	0
STAGE 2	SRB 1X3	C 2 1	834850	112000	5000	0	2031000	267.2	111	7.72	1987.1	13000000	0	0
	SRB 1X4	C 2 2	1107000	128100	5000	0	2353000	267.2	125.4	7.72	1987.1	15000000	0	0
	SRB 1X5	C 2 3	1380570	143800	5000	0	2335500	266.2	157.4	7.72	2278.4	17000000	0	0
STAGE 3	CENT D1-T	C 3 1	30000	4850	1500	275	30000	444	444	57	43.0	13000000	7435	.12
	CENT UB	C 3 2	45000	6640	1500	275	33000	448	611	57	43.0	21000000	8950	.10
	TIT34D 2ND	C 3 3	66380	7250	1500	50	100864	316	208	35.4	93.1	10000000	2350	.12
	S-2	C 3 4	38800	6200	1500	3000	170000	280	64	10.0	124.3	3000000	3270	.12
	S-1	C 3 5	96000	9000	1500	100	522400	283	52	10.0	1103	7000000	3410	.12
	SRB 1X1	C 3 6	314000	51120	2500	0	717280	285.2	125	28.3	543.3	9000000	4450	.24
STAGE 4	-NULL 4TH-	C 4 0	0	0	0	0	0		0.00001	0	0	0	0	0
	TIT3 TRAN	C 4 1	23100	4100	0	0	15700	302	444	30	40.0	10000000	0	0
	IUS 2STAGE	C 4 2	27400	4720	0	0	39700	298	247	70	36	30000000	0	0
	CENT D1-T	C 4 3	30000	4850	0	275	30000	444	444	57	43.0	13000000	0	0
	CENT UB	C 4 4	45000	6640	0	275	33000	448	611	57	43.0	21000000	0	0
	S-3	C 4 5	54000	4500	0	0	300000	304	55	10	300.0	2400000	0	0

▷ VALUES REFLECT TOTAL OF EACH ITEM (E.G. [2] 1-SEG SRB'S)

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Table 3.3-5. Stage and System Cost Characteristics

- ONLY USE FOR RELATIVE COSTING
- 1982 DOLLARS (MILLIONS)
- ONLY STS SRB ZERO AND FIRST STAGES CONSIDERED REUSABLE
- BASED ON APPROX 150 FLIGHTS

STAGE/SYSTEM	AVERAGE UNIT COST [9] EXPENDABLE	REUSABLE [1]	DEV. COST 0/1 STG	UPPER STG
STS SRB				
1 SEG	9.0 [2]	4.5	MOD	HIGH
2 SEG	11.0	-	-	HIGH
3 SEG	13.0	5.5	LOW	MOD
4 SEG	15.0	7.0 [2]	NIL	LOW
5 SEG	17.0	8.5	LOW	MOD
TITAN STRAPONS [3]				
5 SEG	7.5		NIL	
7 SEG	9.0		LOW	
DELTA CASTORS [4]	0.4			
S1 WITH AVIONICS [5]	7.0			?
S2 W/O AVIONICS [5]	3.0			?
S3 W/O AVIONICS [5]	2.4			?
CENTAUR [7]	13			LOW
WB CENTAUR [7]	21			V.HIGH
IUS [7]	30 [8]			NIL
TRANSTAGE (AVIONICS) [7]	10			NIL
TITAN 2ND [6]	10			NIL

[1] BASED ON 20 REUSES [2] FROM MSFC; OTHER SRB'S EXTRAPOLATED BY BAC
[3] CSD [4] THIOKOL [5] MARTIN [6] BAC EST. [7] FROM MSFC
[8] BASED ON A FEW UNITS PER YEAR [9] STEEL CASES

a. Cost per payload pound delivered to destination.

b. Facility impact—qualitative.

c. Stage development cost—qualitative.

d. Maximum thrust-to-weight ratio of 8—assumes tailoring could reduce to 4.

e. Liftoff thrust-to-weight ratio exceeding 1.1.

f. GLOW not to exceed 6,000,000 lb.

3.3.3 Class A Vehicle Results

The performance and vehicle characteristics of each candidate (for all classes) were compiled in the format shown in table 3.3-6. In this case, a LEO mission was performed. Key outputs include payload, thrust-to-weight ratio, velocity split, shroud weight, and total liftoff weight.

Vehicle options for all classes were compared using several methods. The first involved a sequential listing of the best to worst, in terms of payload capability and cost per pound of payload delivered to destination. A second method was to look separately at three- and four-stage vehicles and compare the individual stage options in terms of vehicle level performance.

3.3.3.1 Sequential Comparison

A partial listing of the LEO capability of class A vehicles is shown in table 3.3-7. A complete listing is provided in appendix A. As would be expected, the highest payload capability is provided by concepts using four stages, strapons, and advanced cryogenic upper stages (widebody Centaur). A capability of nearly 80,000 lb was provided by a concept using four one-segment strapons, four-segment stage 1, two-segment stage 2, one-segment stage 3, and a widebody Centaur. A total of 236 concepts satisfied the target requirement of 35,000 lb.

A partial listing of the cost-per-pound comparison is shown in table 3.3-8. It will be noted that the cheapest vehicle employs the use of several DOD SRM's (S1 and S3), which is considerably different from the best payload capability vehicle. The payload capability of this vehicle is down considerably (52,000 lb versus 80,000 lb).

The ranking of the vehicles in terms of GEO payload capability is presented in table 3.3-9. The best vehicle for this application provides nearly 16,000 lb and includes most of the same elements as the best LEO vehicle, with the exception of the third stage. A complete listing for GEO capability is also provided in appendix A. A total of 90 concepts satisfied the target value of 7000 lb.

Table 3.3-6. Class A Performance Output

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STAGE NUM.	MOTOR TYPE	PROPELLANT	INERT	INTERSTAGE	START	BURNOUT	VACUUM THRUST	ISP	BURN TIME	THRUST/WEIGHT INITIAL	THRUST/WEIGHT FINAL	IDEAL V
0	-NULL 0TH-	0	0	0	1699870	1699870	0	0	.00001	1.54397	1.6766	.124017E
1	SRB 1X4	1107000	146300	5000	1699870	592873	2850000	267.2	125.6	1.54397	4.8071	9054.94
2	SRB 1X1	314000	52920	2500	441573	127573	717280	285.2	125	1.62438	5.62263	11392.9
3	CENT DI-T	30000	4850	1500	61518.3	31518.3	30000	444	444	.48766	.951828	3553.05
4	-NULL 4TH-	0	0	0	26668.3	26668.3	0	0	.00001	0	0	0
	TOTALS	1451000	204070	7500	-------	------	------	----	694.6	-------	-------	30000.9

CONFIG. 0 1 1 1 0 : PL WT= 26668.3 SHROUD WT= 10634.2 PL/GLOW=.156884E-01

STAGE NUM.	MOTOR TYPE	PROPELLANT	INERT	INTERSTAGE	START	BURNOUT	VACUUM THRUST	ISP	BURN TIME	THRUST/WEIGHT INITIAL	THRUST/WEIGHT FINAL	IDEAL V
0	-NULL 0TH-	0	0	0	1724730	1724730	0	0	.00001	1.52172	1.65243	.124017E
1	SRB 1X4	1107000	146300	5000	1724730	617731	2850000	267.2	125.6	1.52172	4.61366	8826.65
2	SRB 1X1	314000	52920	2500	466431	152431	717280	285.2	125	1.53781	4.70562	10262
3	CENT WB	45000	6640	1500	84749.6	39749.6	33000	448	611	.389382	.830197	10912.3
4	-NULL 4TH-	0	0	0	33109.6	33109.6	0	0	.00001	0	0	0
	TOTALS	1466000	205860	7500	-------	------	------	----	861.6	-------	-------	30001

CONFIG. 0 1 1 2 0 : PL WT= 33109.6 SHROUD WT= 12261 PL/GLOW=.019197

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Table 3.3-7. Class A LEO Payload

CONFIG CODE	STRAP-ONS	1ST STAGE	2ND STAGE	3RD STAGE	4TH STAGE	PAYLOAD	$PAYLOAD
4 2 2 6	4SRB 4X1 FB	SRB 1X4 SO	SRB 1X2	SRB 1X1	CENT WB	79575.0	2
4 2 2 3	4SRB 4X1 FB	SRB 1X4 SO	SRB 1X2	TIT34D 2ND	CENT WB	78253.1	2.13
4 2 2 5	4SRB 4X1 FB	SRB 1X4 SO	SRB 1X2	S-1	CENT WB	78112.1	2.1
3 2 2 6	4SRB 3X1 FB	SRB 1X4 SO	SRB 1X2	SRB 1X1	CENT WB	73887.4	2.46
3 2 2 3	4SRB 3X1 FB	SRB 1X4 SO	SRB 1X2	TIT34D 2ND	CENT WB	72865.9	2.21
3 2 2 5	4SRB 3X1 FB	SRB 1X4 SO	SRB 1X2	S-1	CENT WB	72729.8	2.19
2 2 2 6	4TIT3 4TH	SRB 1X4 SO	SRB 1X2	SRB 1X1	CENT WB	72647.9	2.1
4 2 1 6	4SRB 4X1 FB	SRB 1X4 SO	SRB 1X1	SRB 1X1	CENT WB	72444.3	1.97
4 2 1 3	4SRB 4X1 FB	SRB 1X4 SO	SRB 1X1	TIT34D 2ND	CENT WB	71572.3	2.12
2 2 2 3	4TIT3 4TH	SRB 1X4 SO	SRB 1X2	TIT34D 2ND	CENT WB	71352.0	2.26
4 2 1 5	4SRB 4X1 FB	SRB 1X4 SO	SRB 1X1	S-1	CENT WB	71257.2	2.49
2 2 2 5	4TIT3 3TH	SRB 1X4 SO	SRB 1X2	S-1	CENT WB	71249.2	2.23
4 2 2 3	3SRB 4X1 FB	SRB 1X4 SO	SRB 1X2	TIT34D 2ND	CENT D1-T	70881.9	1.94
4 2 2 5	3SRB 4X1 FB	SRB 1X4 SO	SRB 1X2	S-1	CENT D1-T	70639.6	1.92
4 2 2 6	3SRB 4X1 FB	SRB 1X4 SO	SRB 1X2	SRB 1X1	CENT D1-T	70234.7	1.77
4 2 2 4	4SRB 4X1 FB	SRB 1X4 SO	SRB 1X2	S-2	CENT WB	69482	1.9
1 2 2 6	4SRB 2X1 FB	SRB 1X4 SO	SRB 1X2	SRB 1X1	CENT WB	68359.5	2.12
3 2 1 6	4SRB 3X1 FB	SRB 1X4 SO	SRB 1X1	SRB 1X1	CENT WB	67147.1	2.34
1 2 2 3	4SRB 2X1 FB	SRB 1X4 SO	SRB 1X2	TIT34D 2ND	CENT WB	67473.5	2.31
1 2 2 5	4SRB 2X1 FB	SRB 1X4 SO	SRB 1X2	S-1	CENT WB	66949.5	2.28
3 2 1 3	4SRB 3X1 FB	SRB 1X4 SO	SRB 1X1	TIT34D 2ND	CENT WB	66554	2.23
3 2 1 5	4SRB 3X1 FB	SRB 1X4 SO	SRB 1X1	S-1	CENT WB	66231.9	2.19
3 2 2 3	3SRB 3X1 FB	SRB 1X4 SO	SRB 1X2	TIT34D 2ND	CENT D1-T	65820.8	2.21
2 2 1 6	4TIT3 3TH	SRB 1X4 SO	SRB 1X1	SRB 1X1	CENT WB	65663.0	2.38
3 2 2 5	3SRB 3X1 FB	SRB 1X4 SO	SRB 1X2	S-1	CENT D1-T	65555.5	1.99
3 2 2 6	3SRB 3X1 FB	SRB 1X4 SO	SRB 1X2	SRB 1X1	CENT D1-T	64985.6	1.82
4 2 1 3	3SRB 4X1 FB	SRB 1X4 SO	SRB 1X1	TIT34D 2ND	CENT D1-T	64781.5	1.93
2 2 1 3	4TIT3 3TH	SRB 1X4 SO	SRB 1X1	TIT34D 2ND	CENT WB	64787.4	2.27
4 2 2 6	5SRB 4X1 FB	SRB 1X4 SO	SRB 1X2	SRB 1X1	S-3	64565.6	1.62
2 2 1 5	4TIT3 3TH	SRB 1X4 SO	SRB 1X1	S-1	CENT WB	64458.6	2.23
3 2 2 4	4SRB 3X1 FB	SRB 1X4 SO	SRB 1X2	S-2	CENT WB	64394.7	1.98
2 2 2 3	3TIT3 3TH	SRB 1X4 SO	SRB 1X2	TIT34D 2ND	CENT D1-T	64352.4	2.35
4 2 1 5	3SRB 4X1 FB	SRB 1X4 SO	SRB 1X1	S-1	CENT D1-T	64289.3	1.9
2 2 2 5	3TIT3 3TH	SRB 1X4 SO	SRB 1X2	S-1	CENT D1-T	64138	2.23
4 2 2 3	5SRB 4X1 FB	SRB 1X4 SO	SRB 1X2	TIT34D 2ND	S-3	63837.8	1.74
4 2 2 5	5SRB 4X1 FB	SRB 1X4 SO	SRB 1X2	S-1	S-3	63641.6	1.72
2 2 2 6	3TIT3 3TH	SRB 1X4 SO	SRB 1X2	SRB 1X1	CENT D1-T	63618.2	1.85
4 2 1 4	4SRB 4X1 FB	SRB 1X4 SO	SRB 1X1	S-2	CENT WB	63521.4	1.9
4 2 1 6	3SRB 4X1 FB	SRB 1X4 SO	SRB 1X1	SRB 1X1	CENT D1-T	63420.6	1.73
2 2 2 4	4TIT3 3TH	SRB 1X4 SO	SRB 1X2	S-2	CENT WB	62955.2	2.42
4 2 2 2	1SRB 4X1 FB	SRB 1X4 SO	SRB 1X2	CENT WB	TIT3 TRAN	[illegible]	1.72
4 2 2 2	2SRB 4X1 FB	SRB 1X4 SO	SRB 1X2	CENT WB			
1 2 1 6	4SRB 2X1 FB	SRB 1X4 SO	SRB 1X1	SRB [illegible]			
1 2 1 3	4SRB 2X1 FB	SRB 1X4 SO	SRB 1X1				
4 2 2 4	3SRB 4X1 FB	SRB 1X1 SO	SRB				

Table 3.3-8. Class A LEO Payload Cost per Pound

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CONFIG.	BOOSTER ▷1	1ST STAGE	2ND STAGE	3RD STAGE	4TH STAGE	COST/LB	COST	PAYLOAD	%PAYLOAD
1 2 2 5	5SRB 2X1 FB	SRB 1X4 SO	SRB 1X2	S-1	S-3	683.398	.364E+08	53263.2	1.82
3 2 2 5	5SRB 3X1 FB	SRB 1X4 SO	SRB 1X2	S-1	S-3	697.693	.409E+08	58621.3	1.77
0 1 2 5	5-NULL 0TH-	SRB 1X4	SRB 1X2	S-1	S-3	708.046	.274E+08	38698.1	1.21
1 2 2 4	5SRB 2X1 FB	SRB 1X4 SO	SRB 1X2	S-2	S-3	708.143	.324E+08	45753.4	1.6
1 2 2 6	5SRB 2X1 FB	SRB 1X4 SO	SRB 1X2	SRB 1X1	S-3	713.235	.384E+08	53839.2	1.69
4 2 2 5	5SRB 4X1 FB	SRB 1X4 SO	SRB 1X2	S-1	S-3	713.37	.454E+08	63641.6	1.72
0 1 2 4	5-NULL 0TH-	SRB 1X4	SRB 1X2	S-2	S-3	720.184	.234E+08	32491.7	1.57
1 2 1 5	5SRB 2X1 FB	SRB 1X4 SO	SRB 1X1	S-1	S-3	722.708	.344E+08	47598.8	1.81
3 2 2 6	5SRB 3X1 FB	SRB 1X4 SO	SRB 1X2	SRB 1X1	S-3	723.056	.429E+08	59331.5	1.65
3 2 2 4	5SRB 3X1 FB	SRB 1X4 SO	SRB 1X2	S-2	S-3	728.525	.369E+08	50650.3	1.56
4 2 2 6	5SRB 4X1 FB	SRB 1X4 SO	SRB 1X2	SRB 1X1	S-3	734.364	.474E+08	64545.6	1.62
1 2 2 3	5SRB 2X1 FB	SRB 1X4 SO	SRB 1X2	TIT34D 2ND	S-3	737.309	.394E+08	53437.6	1.85
1 2 1 4	5SRB 2X1 FB	SRB 1X4 SO	SRB 1X1	S-2	S-3	738.973	.304E+08	41138.2	1.61
3 2 1 5	5SRB 3X1 FB	SRB 1X4 SO	SRB 1X1	S-1	S-3	738.978	.389E+08	52640.3	1.75
2 2 2 5	5TIT3 0TH	SRB 1X4 SO	SRB 1X2	S-1	S-3	740.773	.424E+08	57237.5	1.8
3 2 2 3	5SRB 3X1 FB	SRB 1X4 SO	SRB 1X2	TIT34D 2ND	S-3	746.447	.439E+08	58811.9	1.79
4 2 2 4	5SRB 4X1 FB	SRB 1X4 SO	SRB 1X2	S-2	S-3	749.35	.414E+08	55247.9	1.52
4 2 1 5	5SRB 4X1 FB	SRB 1X4 SO	SRB 1X1	S-1	S-3	757.544	.434E+08	57290.4	1.68
4 2 2 3	5SRB 4X1 FB	SRB 1X4 SO	SRB 1X2	TIT34D 2ND	S-3	758.171	.484E+08	63837.8	1.74
0 1 1 4	5-NULL 0TH-	SRB 1X4	SRB 1X1	S-2	S-3	759.676	.214E+08	28169.9	1.59
0 1 1 5	5-NULL 0TH-	SRB 1X4	SRB 1X1	S-1	S-3	761.537	.254E+08	33353.6	1.82
1 2 1 6	5SRB 2X1 FB	SRB 1X4 SO	SRB 1X1	SRB 1X1	S-3	761.759	.364E+08	47784.2	1.65
3 2 1 4	5SRB 3X1 FB	SRB 1X4 SO	SRB 1X1	S-2	S-3	763.346	.349E+08	45719.8	1.55
2 2 2 6	5TIT3 0TH	SRB 1X4 SO	SRB 1X2	SRB 1X1	S-3	764.454	.444E+08	58080.7	1.68
3 2 1 6	5SRB 3X1 FB	SRB 1X4 SO	SRB 1X1	SRB 1X1	S-3	771.851	.409E+08	52989.5	1.61
2 2 2 4	5TIT3 0TH	SRB 1X4 SO	SRB 1X2	S-2	S-3	778.481	.384E+08	49326.8	1.58

▷1 STRAP-ONS

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SRB-X-62

Table 3.3-9. Class A GEO Payload

code CONFIG	BOOSTER [1]	1ST STAGE	2ND STAGE	3RD STAGE	4TH STAGE	PAYLOAD	ΔPAYLOAD
4 2 2 3	4SRB 4X1 FB	SRB 1X4 SO	SRB 1X2	TIT34D 2ND	CENT 48	15753.2	.43
4 2 2 5	4SRB 4X1 FB	SRB 1X4 SO	SRB 1X2	S-1	CENT 48	15549.8	.42
3 2 2 3	4SRB 3X1 FB	SRB 1X4 SO	SRB 1X2	TIT34D 2ND	CENT 48	14683.5	.45
4 2 1 3	4SRB 4X1 FB	SRB 1X4 SO	SRB 1X1	TIT34D 2ND	CENT 48	14491.5	.43
3 2 2 5	4SRB 3X1 FB	SRB 1X4 SO	SRB 1X2	S-1	CENT 48	14439.1	.44
2 2 2 3	4TIT3 3TH	SRB 1X4 SO	SRB 1X2	TIT34D 2ND	CENT 48	14261.5	.46
4 2 2 5	4SRB 4X1 FB	SRB 1X4 SO	SRB 1X2	SRB 1X1	CENT 48	14196.9	.35
4 2 1 5	4SRB 4X1 FB	SRB 1X4 SO	SRB 1X1	S-1	CENT 48	14195	.42
2 2 2 5	4TIT3 3TH	SRB 1X4 SO	SRB 1X2	S-1	CENT 48	13876.1	.45
4 2 2 3	3SRB 4X1 FB	SRB 1X4 SO	SRB 1X2	TIT34D 2ND	CENT D1-T	13847	.38
4 2 2 5	3SRB 4X1 FB	SRB 1X4 SO	SRB 1X2	S-1	CENT D1-T	13535.3	.37
3 2 1 3	4SRB 3X1 FB	SRB 1X4 SO	SRB 1X1	TIT34D 2ND	CENT 48	13386.7	.45
1 2 2 3	4SRB 2X1 FB	SRB 1X4 SO	SRB 1X2	TIT34D 2ND	CENT 48	13349.5	.47
1 2 2 5	4SRB 2X1 FB	SRB 1X4 SO	SRB 1X2	S-1	CENT 48	13159.1	.45
3 2 2 5	4SRB 3X1 FB	SRB 1X4 SO	SRB 1X2	SRB 1X1	CENT 48	13123.8	.37
3 2 1 5	4SRB 3X1 FB	SRB 1X4 SO	SRB 1X1	S-1	CENT 48	13122.7	.44
2 2 1 3	4TIT3 3TH	SRB 1X4 SO	SRB 1X1	TIT34D 2ND	CENT 48	12944.9	.45
4 2 2 4	4SRB 4X1 FB	SRB 1X4 SO	SRB 1X2	S-2	CENT 48	12875.9	.35
2 2 2 5	4TIT3 3TH	SRB 1X4 SO	SRB 1X2	SRB 1X1	CENT 48	12855.5	.34
3 2 2 3	3SRB 3X1 FB	SRB 1X4 SO	SRB 1X2	TIT34D 2ND	CENT D1-T	12837.6	.4
4 2 1 5	4SRB 4X1 FB	SRB 1X4 SO	SRB 1X1	SRB 1X1	CENT 48	12834.5	.35
4 2 1 3	3SRB 4X1 FB	SRB 1X4 SO	SRB 1X1	TIT34D 2ND	CENT D1-T	12747.8	.38
2 2 1 5	4TIT3 3TH	SRB 1X4 SO	SRB 1X1	S-1	CENT 48	12683.3	.44
3 2 2 5	3SRB 3X1 FB	SRB 1X4 SO	SRB 1X2	S-1	CENT D1-T	12518.5	.36
2 2 2 3	3TIT3 3TH	SRB 1X4 SO	SRB 1X2	TIT34D 2ND	CENT D1-T	12595	.4
4 2 1 5	3SRB 4X1 FB	SRB 1X4 SO	SRB 1X1	S-1	CENT D1-T	12388.7	.37
2 2 2 5	3TIT3 3TH	SRB 1X4 SO	SRB 1X2	S-1	CENT D1-T	12226.1	.39
1 2 1 3	4SRB 2X1 FB	SRB 1X4 SO	SRB 1X1	TIT34D 2ND	CENT 48	12150.9	.47
1 2 2 5	4SRB 2X1 FB	SRB 1X4 SO	SRB 1X2	SRB 1X1	CENT 48	11962	.38
4 2 1 4	4SRB 4X1 FB	SRB 1X4 SO	SRB 1X1	S-2	CENT 48	11945.5	.35
1 2 1 5	4SRB 2X1 FB	SRB 1X4 SO	SRB 1X1	S-1	CENT 48	11883.5	.45
3 2 2 4	4SRB 3X1 FB	SRB 1X4 SO	SRB 1X2	S-2	CENT 48	11881.6	.37
3 2 1 3	3SRB 3X1 FB	SRB 1X4 SO	SRB 1X1	TIT34D 2ND	CENT D1-T	11828.9	.1
3 2 1 5	4SRB 3X1 FB	SRB 1X4 SO	SRB 1X1	SRB 1X1	CENT 48	11776	.36
1 2 2 3	3SRB 2X1 FB	SRB 1X4 SO	SRB 1X2	TIT34D 2ND	CENT D1-T	11710.7	.41

[1] STRAP-ONS

3.3.3.2 Stage-by-Stage Comparison

In this comparison, a reference vehicle was selected and each stage was investigated separately using its various options to determine their impacts. The abbreviations and codes used for this comparison are shown in figure 3.3-1. Comparison of three-stage vehicles is presented in tables 3.3-10 and -11. Four-stage vehicles are compared in tables 3.3-12 and -13.

3.3.3.3 Conclusions and Recommendations

The conclusions and observations resulting from the class A analysis are presented in table 3.3-14. The concepts recommended for further investigation and supporting rationale are presented in table 3.3-15. It will be noted that the concepts have been grouped into "families" with a three-stage vehicle being used for polar missions and a fourth stage (Centaur) added to provide maximum LEO and GEO capability.

3.3.4 Class B Vehicle Results

3.3.4.1 Sequential Comparison

A partial listing of LEO and GEO capability for class B vehicles is shown in tables 3.3-16 and -17, respectively. A complete listing of those concepts satisfying the screening criteria is provided in appendix A. In the case of LEO capability, nearly 85,000 lb was possible with a configuration consisting of: two four-segment SRB's for stage 1, one five-segment SRB for stage 2, one one-segment SRB for stage 3, and a widebody Centaur for stage 4. A total of 38 concepts satisfied the target requirement of 65,000 lb, with all involving four-stage vehicles.

Maximum GEO capability obtained was nearly 15,300 lb. The associated configuration was considerably different from the LEO vehicle inasmuch as stage 1 employed two five-segment SRB's; stage 2, one two-segment SRB; stage 3, a Titan second stage; however, stage 4 was common in the form of the widebody Centaur. The maximum LEO capability vehicle was not far behind in terms of GEO capability at 15,000 lb. A total of 32 concepts provided the target payload of 12,000 lb.

3.3.4.2 Stage-by-Stage Comparison

Again, this comparison investigated each stage, one at a time, and the options associated with that stage in terms of vehicle level impact. Comparison of three-stage vehicles is presented in tables 3.3-18 and -19 and four-stage vehicles in tables 3.3-20 and -21. Some of the more interesting concepts are summarized in table 3.3-22.

ABBREV.	NAME
1 (X)	1 SEGMENT SRB (NUMBER INDICATES QTY)
2	2 SEGMENT SRB
3	3 SEGMENT SRB
4	4 SEGMENT SRB
5	5 SEGMENT SRB
T05	TITAN STRAP-ON 5 SEGMENT (2)
T07	TITAN STRAP-ON 7 SEGMENT (2)
DC	DELTA CASTORS (14)
S1	1ST STAGE LAND LAUNCHED MISSILE
S2	1ST STAGE SEA LAUNCHED MISSILE
S3	2ND STAGE LAND LAUNCHED MISSILE
C	CENTAUR D1-T
WBC	WIDE BODY CENTAUR
T2	TITAN 2ND STAGE
IUS	INERTIAL UPPER STAGE
TT	TITAN TRANSTAGE
D2	DELTA 2ND STAGE
T1	TITAN 1ST STAGE

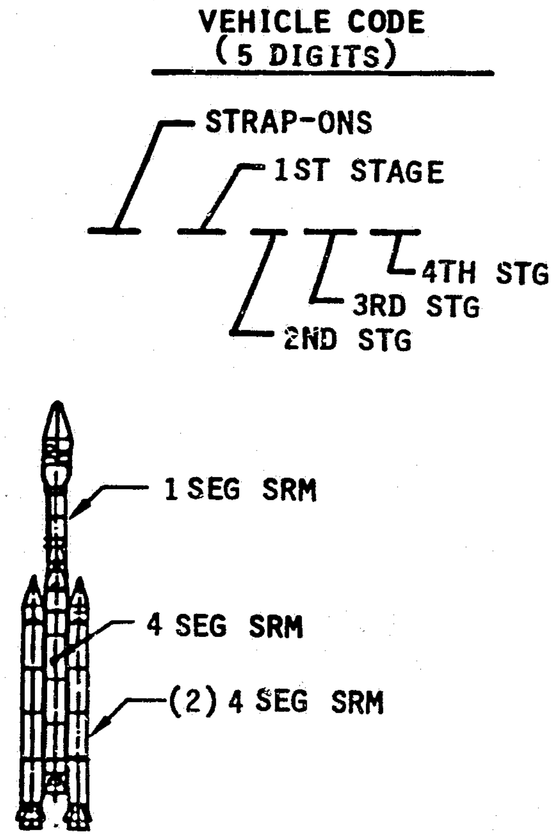

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Figure 3.3-1. Abbreviations and Codes

Table 3.3-10. Class A Three-Stage Vehicles

• BEST SECOND STAGE (FIXED 1ST AND 3RD)

OPTION	PAYLOAD (K LBS)		COST/LBS		OTHER FACTORS/ COMMENTS
	LEO	GEO	LEO	GEO	MAX G
* 0-4-1-C-0	26.7	3.3	1090	8790	5.6
0-4-2-C-0	29.4	3.6	1050	8600	10.5

• BEST THIRD STAGE (USING GOOD SECOND STAGE)

* 0-4-1-C-0	26.7	3.3	1050	8790	5.6
0-4-1-WBC-0	33.1	4.4	1117	8440	4.7
* 0-4-1-T2-0	25.4	< 0	1020		4.5
0-4-1-S3-0	15.7	< 0			
0-4-1-S1-0	23.3	< 0			
0-4-1-1-0	0.3	< 0			

• OTHER INTERESTING CONCEPTS

* 0-4-2-T2-0	29.3	0.2	960	—	7.0 (TO LEO)

CONCLUSION: BEST 3 STAGE OPTION FOR BOTH MISSIONS: 4-1-C
RETAIN 4-2-T2 AND 4-1-T2 FOR 4 STAGE VEHICLE

* SELECTION FOR THE INDICATED COMPARISON PARAMETER

Table 3.3-11. Class A Three-Stage Vehicles (Continued)

- BEST ZERO STAGE (STRAPONS) – WITH GOOD 3 STAGE VEHICLE

OPTION	PAYLOAD (K LBS)		COST ($/LB)		OTHER FACTORS/COMMENTS	
	LEO	GEO	LEO	GEO	MAX G	
0-4-1-C-0	26.7	3.3	1090	8790	5.6	PAYLOAD TOO LOW
* 1(2)-4-1-C-0	38.7	5.6	980	6840	6.9	LIFTOFF T/W MARG.
1(3)-4-1-C-0	42.9	6.3	990	6740	6.8	FACILITY AND/OR LIFTOFF G PROB.
1(4)-4-1-C-0	46.8	7.0	1000	6750	6.8	
(14)DC-4-1-C-0	30.6	4.1	1410	10590	7.0	PAYLOAD TOO LOW
* T05-4-1-C-0	41.3	6.0	1160	7330	6.9	LEAST Δ DEV COST
T07-4-1-C-0	45.8	6.8	1030	6900	6.8	

- OTHER INTERESTING CONCEPTS

T05-4-2-C					
T07-4-2-C	53.1	7.5	922		10.8

CONCLUSION: ALL HAVE MLP FLAME HOLE CHALLENGE
RETAIN TITAN 7 SEG AND 5 SEG STRAPONS AND POSSIBLY (2) 1 SEG SRB

* SELECTION FOR INDICATED COMPARISON PARAMETER

Table 3.3-12. *Class A Four-Stage Vehicles*

SRB-X-73

● BEST FOURTH STAGE (WITH GOOD 3 STAGE VEHICLE)

OPTION	PAYLOAD (K LBS) LEO	PAYLOAD (K LBS) GEO	COST ($/LB) LEO	COST ($/LB) GEO	OTHER FACTORS/COMMENTS MAX G	
0-4-1-C-0	26.7	3.3	1090	8790	5.6	
✓ 0-4-1-C-TT	27.8	2.3	1400	16940	5.6	
0-4-1-C-IUS *	27.7	1.7	2130	34700	5.4	
0-4-1-C-C	39.3	7.5	1070	5590	5.1	PROPER SHROUD NOT INCLUDED COMPLEXITY
0-4-1-C-WBC	44.1	8.2	1130	6070	4.6	
0-4-1-C-S3	32.7	3.3	980	9700	7.1	

CONCLUSION: 4TH STAGE DOESN'T HELP WITH CENTAUR 3RD STAGE

● OTHER INTERESTING CONCEPTS

✓ 0-4-1-T2-C	40.2	7.5	970	5200	4.5	LESS HT
✓ 0-4-2-T2-C	45.4	8.5	900	4800	6.6	

CONCLUSION: RETAIN TITAN 2ND AS THIRD STAGE FOR LEO AND ADD CENTAUR FOR GEO MISSIONS

✓ SELECTION FOR INDICATED COMPARISON PARAMETER

* MODIFIED IUS

Table 3.3-13. Class A Four-Stage Vehicles (Continued)

• BEST ZERO STAGE (STRAP-ONS) — WITH BEST 4 STAGE VEHICLE

OPTION	PAYLOAD (K LBS)		COST ($/LB)		OTHER FACTORS
	LEO	GEO	LEO	GEO	MAX G
0-4-1-T2-C	40.2	7.5	970	5200	4.5
* 1(2)-4-1-T2-C	54.9	10.8	870	4460	4.4
1(3)-4-1-T2-C	60.1	11.8	870	4440	4.4
1(4)-4-1-T2-C	64.8	12.8	880	4460	4.4
DC-4-1-T2-C	44.4	8.4	1190	6340	4.4
* T05-4-1-T2-C	58.3	11.4	930	4720	4.4
* T07-4-1-T2-C	62.6	12.2	910	4670	4.4

• OTHER INTERESTING CONCEPTS

T07-4-2-T2-C	67.7	13.0	870	4730	6.3
T07-3-1-T2-C					

* RETAIN TITAN AND (2) 1-SEGMENT STRAP-ONS FOR FURTHER COMPARISON

Table 3.3-14. Conclusions and Observations

- 3 STAGE VEHICLES EVEN WITH STRAPONS HAVE MARGINAL GEO PERFORMANCE
- 4 STAGE VEHICLES WITHOUT STRAPONS HAVE ADEQUATE PERFORMANCE (8K TO GEO)
- STRAPONS BOOST 4 STAGE PERFORMANCE TO CLASS B (TWO BOOSTER) LEVEL
- STANDARD CENTAUR IS ADEQUATE AS FOURTH STAGE
- "GOOD" VEHICLE: 4 SEG BOOSTER; 1 SEG SRM; TITAN 2ND STAGE; D-IT CENTAUR
  - COULD OPERATE AS THREE OR FOUR STAGE VEHICLE
  - TITAN 2ND STAGE/CENTAUR INTEGRATION HAS BEEN DONE
- OBSERVATIONS:
  - TITAN 2ND STAGE GOOD MATCH IN STACK
    - RESTART APPEARS READILY AVAILABLE – BETTER LEO PERFORMANCE THEN CENTAUR
  - 1 SEG VERSUS 2 SEG SECOND STAGE – OPEN ISSUE
    - OPTIMIZATION OF SECOND STAGE NEEDS TO BE DONE
  - TITAN (120" SRM) IS ATTRACTIVE – PARTICULARLY IF USE OF TITAN FACILITIES IS FEASIBLE

Table 3.3-15. Recommended Class A Concepts

FAMILY	CONFIGURATION CODE	APPLICATION [1]	RATIONALE FOR CONTINUED INVESTIGATION
1	0-4-1-C-0 T05-4-1-C-0	L, P, G L, P, G	• BASIC REF VEHICLE - MSFC CONFIG 3 • RETAIN UNTIL POST TRAJECTORY ANALYSIS IS COMPLETED
2	0-4-1-T2-0 0-4-1-T2-C	P L, G	• 1 VERSUS 2 SEG TRADE HT, STABIL, FACIL, PERF TRADE-OFFS • T2 PROVIDES NON-CRYO LEO/POLAR CAPABILITY
3	0-4-2-T2-0 0-4-2-T2-C	P L, G	
4	T05-4-1-T2-0 T05-4-1-T2-C	P L, G	• ENHANCES BLOCK 2 PERF FOR 1990 – 95 REQUIREMENTS • 1 SEG IS ADEQUATE WITH STRAP-ONS
5	1(2)-4-1-T2-0 1(2)-4-1-T2-C	P L, G	• IF STS FACIL PROVE MORE DESIRABLE, SRB S/O PROVIDE COMPARABLE PERF AND UNIT COST BUT MORE DEV COST THAN BLOCK 3 • MINIMUM VEHICLE DEVELOPMENT COST

[1] P – POLAR, L – LEO, G – GEO

Table 3.3-16. Class B LEO Payload

SRB-X-64

code CONFIG.	BOOSTER	1ST STAGE	2ND STAGE	3RD STAGE	4TH STAGE	PAYLOAD	$PAYLOAD
2 4 5	4-NULL 0TH-	SRB 2X4	SRB 1X5	SRB 1X1	CENT #8	84846.3	1.95
3 1 5	4-NULL 0TH-	SRB 2X5	SRB 1X2	SRB 1X1	CENT #8	80367.5	1.85
2 3 5	4-NULL 0TH-	SRB 2X4	SRB 1X4	SRB 1X1	CENT #8	79713.4	1.96
2 4 5	4-NULL 0TH-	SRB 2X4	SRB 1X5	S-1	CENT #8	78084.3	1.81
3 2 5	4-NULL 0TH-	SRB 2X5	SRB 1X3	S-1	CENT #8	77573.3	1.8
3 1 5	4-NULL 0TH-	SRB 2X5	SRB 1X2	S-1	CENT #8	77096.7	1.91
3 1 3	4-NULL 0TH-	SRB 2X5	SRB 1X2	TIT34D 2ND	CENT #8	76980.3	1.92
2 4 3	4-NULL 0TH-	SRB 2X4	SRB 1X5	TIT34D 2ND	CENT #8	76834.1	1.8
3 2 3	4-NULL 0TH-	SRB 2X5	SRB 1X3	TIT34D 2ND	CENT #8	76779.5	1.79
2 4 6	3-NULL 0TH-	SRB 2X4	SRB 1X5	SRB 1X1	CENT D1-T	75885.7	1.54
1 4 5	4-NULL 0TH-	SRB 2X3	SRB 1X5	SRB 1X1	CENT #8	74752.8	1.87
2 3 5	4-NULL 0TH-	SRB 2X4	SRB 1X4	S-1	CENT #8	73964.3	1.84
2 2 5	4-NULL 0TH-	SRB 2X4	SRB 1X3	SRB 1X1	CENT #8	73742	1.81
2 3 3	4-NULL 0TH-	SRB 2X4	SRB 1X4	TIT34D 2ND	CENT #8	73038.3	1.83
2 1 5	4-NULL 0TH-	SRB 2X4	SRB 1X2	SRB 1X1	CENT #8	73924.4	1.91
3 1 6	3-NULL 0TH-	SRB 2X5	SRB 1X2	SRB 1X1	CENT D1-T	73867.9	1.65
2 3 6	3-NULL 0TH-	SRB 2X4	SRB 1X4	SRB 1X1	CENT D1-T	73133.1	1.64
1 3 6	4-NULL 0TH-	SRB 2X3	SRB 1X4	SRB 1X1	CENT #8	69730.3	1.8
2 4 5	3-NULL 0TH-	SRB 2X4	SRB 1X5	S-1	CENT D1-T	69583.3	1.62
3 2 5	3-NULL 0TH-	SRB 2X5	SRB 1X3	S-1	CENT D1-T	69444.6	1.62
3 1 5	3-NULL 0TH-	SRB 2X5	SRB 1X2	S-1	CENT D1-T	69421.3	1.73
2 4 5	5-NULL 0TH-	SRB 2X4	SRB 1X5	SRB 1X1	S-3	69381.8	1.31
3 1 3	3-NULL 0TH-	SRB 2X5	SRB 1X2	TIT34D 2ND	CENT D1-T	69387.3	1.74
2 2 5	4-NULL 0TH-	SRB 2X4	SRB 1X3	S-1	CENT #8	58780.8	1.85
3 2 3	3-NULL 0TH-	SRB 2X5	SRB 1X3	TIT34D 2ND	CENT D1-T	68657.9	1.51
1 4 5	4-NULL 0TH-	SRB 2X3	SRB 1X5	S-1	CENT #8	68529.4	1.84
2 4 3	3-NULL 0TH-	SRB 2X4	SRB 1X5	TIT34D 2ND	CENT D1-T	68359.9	1.61
2 1 5	4-NULL 0TH-	SRB 2X4	SRB 1X2	S-1	CENT #8	68152.7	1.98
2 2 3	4-NULL 0TH-	SRB 2X4	SRB 1X3	TIT34D 2ND	CENT #8	68045.7	1.84
2 1 3	4-NULL 0TH-	SRB 2X4	SRB 1X2	TIT34D 2ND	CENT #8	67977.1	1.89
3 1 4	4-NULL 0TH-	SRB 2X5	SRB 1X2	S-2	CENT #8	67658.6	1.71
1 4 3	4-NULL 0TH-	SRB 2X3	SRB 1X5	TIT34D 2ND	CENT #8	67416.2	1.83
3 2 4	4-NULL 0TH-	SRB 2X5	SRB 1X3	S-2	CENT #8	66711.4	1.57
2 4 4	4-NULL 0TH-	SRB 2X4	SRB 1X5	S-2	CENT #8	66217.3	1.56
2 3 5	3-NULL 0TH-	SRB 2X4	SRB 1X4	S-1	CENT D1-T	65946.9	1.65
1 4 6	3-NULL 0TH-	SRB 2X3	SRB 1X5	SRB 1X1	CENT D1-T	65369.6	1.65

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Table 3.3-17. Class B GEO Payload

SRB-X-61

code CONFIG.	BOOSTER	1ST STAGE	2ND STAGE	3RD STAGE	4TH STAGE	PAYLOAD	$PAYLOAD
3 1 3	4-NULL ATH-	SR4 2X5	SR8 1X2	TIT340 2ND	CENT 4B	15258.8	.35
3 1 5	4-NULL OTH-	SR8 2X5	SR4 1X2	S-1	CENT 4B	15159.5	.35
2 1 6	4-NULL ATH-	SR3 2X4	SR5 1X5	SR8 1X1	CENT 4B	15012.4	.33
1 2 5	4-NULL OTH-	SR4 2X5	SR8 1X3	S-1	CENT 4B	14958.6	.35
2 1 5	4-NULL ATH-	SR3 2X4	SR8 1X5	S-1	CENT 4B	14858.4	.35
1 2 3	4-NULL ATH-	SR3 2X5	SR8 1X3	TIT340 2ND	CENT 4B	14849.7	.35
2 4 3	4-NULL OTH-	SR3 2X4	SR8 1X5	TIT340 2ND	CENT 4B	14619.5	.31
1 1 6	4-NULL ATH-	SR4 2X5	SR8 1X2	SR8 1X1	CENT 4B	14274.1	.35
2 3 5	4-NULL OTH-	SR4 2X4	SR8 1X4	S-1	CENT 4B	14148.3	.45
2 4 5	4-NULL OTH-	SR3 2X4	SR8 1X4	SR8 1X1	CENT 4B	14076.9	.33
3 1 3	4-NULL ATH-	SR3 2X4	SR8 1X4	TIT340 2ND	CENT 4B	13982.6	.35
2 1 3	4-NULL OTH-	SR3 2X1	SR8 1X2	TIT340 2ND	CENT 4B	13370.7	.4
1 1 3	3-NULL ATH-	SR4 2X5	SR8 1X2	TIT340 2ND	CENT D1-T	13311.2	.44
2 1 5	4-NULL ATH-	SR3 2X4	SR8 1X2	S-1	CENT 4B	13278.9	.39
2 2 5	4-NULL OTH-	SR3 2X4	SR8 1X3	S-1	CENT 4B	13160.5	.35
1 1 5	3-NULL OTH-	SR3 2X5	SR8 1X2	S-1	CENT D1-T	13111.6	.33
1 1 5	4-NULL OTH-	SR3 2X3	SR8 1X5	SR8 1X1	CENT 4B	13111.2	.33
2 2 3	4-NULL OTH-	SR3 2X4	SR8 1X3	TIT340 2ND	CENT 4B	13058.5	.36
2 2 5	4-NULL OTH-	SR3 2X4	SR8 1X3	SR8 1X1	CENT 4B	12918.4	.33
1 3 5	4-NULL ATH-	SR3 2X3	SR8 1X5	S-1	CENT 4B	12944.9	.35
1 2 5	3-NULL OTH-	SR3 2X5	SR8 1X3	S-1	CENT D1-T	12842.1	.3
1 2 3	3-NULL ATH-	SR4 2X5	SR8 1X3	TIT340 2ND	CENT D1-T	12828.6	.4
1 1 3	4-NULL OTH-	SR3 2X3	SR8 1X5	TIT340 2ND	CENT 4B	12721.1	.35
2 1 5	3-NULL OTH-	SR3 2X4	SR8 1X5	S-1	CENT D1-T	12694.2	.3
2 4 3	3-NULL ATH-	SR3 2X4	SR8 1X5	TIT340 2ND	CENT D1-T	12549.2	.4
2 1 5	4-NULL OTH-	SR4 2X4	SR8 1X2	SR8 1X1	CENT 4B	12464.5	.34
1 1 4	4-NULL ATH-	SR4 2X5	SR8 1X2	S-2	CENT 4B	12316.5	.33
1 1 5	4-NULL ATH-	SR3 2X3	SR8 1X4	S-1	CENT 4B	12195.7	.45
1 3 5	4-NULL ATH-	SR3 2X3	SR8 1X4	SR8 1X1	CENT 4B	12161.8	.45
2 1 5	3-NULL OTH-	SR3 2X4	SR8 1X4	S-1	CENT D1-T	12119.5	.3
2 3 3	3-NULL ATH-	SR3 2X3	SR8 1X4	TIT340 2ND	CENT D1-T	12046.8	.3
1 1 3	4-NULL ATH-	SR4 2X3	SR8 1X4	TIT340 2ND	CENT 4B	12039.2	.35
2 1 6	3-NULL ATH-	SR8 2X4	SR8 1X5	SR8 1X1	CENT D1-T	11864.3	.25
1 2 4	4-NULL OTH-	SR3 2X5	SR8 1X3	S-2	CENT 4B	11727.0	.28
2 1 3	3-NULL OTH-	SR4 2X4	SR8 1X2	TIT340 2ND	CENT D1-T	11681.5	.45

Table 3.3-18.- Class B Three-Stage Vehicles

SRB-X-71

● BEST SECOND STAGE (FIXED 1ST AND 3RD)

OPTION	PAYLOAD (K LBS) LEO	PAYLOAD (K LBS) GEO	COST ($/LB) LEO	COST ($/LB) GEO	OTHER FACTORS MAX. G	OTHER FACTORS
✓ 4(2)-4-C-0	40.6	5.0	1030	8390	13.0	MODIF. 2ND STAGE
4(2)-3-C-0	38.0	4.7	1050	8500	9.4	
✓ 4(2)-2-C-0	40.8	5.5	930	6930	9.7	EXTRA DEV $
4(2)-5-C-0	42.3	5.1	1040	8550	11.9	EXTRA DEV $$

● OTHER FIRST/SECOND CONCEPTS

OPTION	PAYLOAD (K LBS) LEO	PAYLOAD (K LBS) GEO	COST ($/LB) LEO	COST ($/LB) GEO	OTHER FACTORS MAX. G
3(2)-3-C-0	31.6	3.7	1171	10020	9.4
3(2)-4-C-0	34.0	4.0	1150	9750	13.1
5(2)-2-C-0	47.7	6.5	860	6270	9.6
✓ 5(2)-3-C-0	44.3	5.6	970	7610	9.3
5(2)-4-C-0					

(LIFTOFF T/W = 1.1 WITH NO PAYLOAD OR SHROUD)

CONCLUSION: RETAIN ✓ ITEMS FOR BEST 3RD STAGE TRADE

Table 3.3-19. *Class B Three-Stage Vehicles (Continued)*

SRB-X-66

OPTION	PAYLOAD (K LBS) LEO	PAYLOAD (K LBS) GEO	COST/LB LEO	COST/LB GEO	OTHER COMMENTS MAX G
● BEST THIRD STG (WITH BEST 1st/2nd COMBINATION)					
✓ 4(2)-2-C-0	40.8	5.5	930	6930	9.7
4(2)-2-WBC-0	50.5	7.5	910	6100	8.4
✓ 4(2)-2-T2-0	42.3	2.4	830	14800	10.5 (T2-GEO)
4(2)-2-S1-0	41.4	0	770	-	10.4 (LEO)
4(2)-2-1-0	27.3	< 0	1240	-	9.1 (LEO)
4(2)-4-1-0	36.0	< 0	1060	-	8.2 (LEO)
✓ 4(2)-4-T2-0	44.0	2.2	890	17520	10.7 (T2-GEO)
● OTHER 1st/2nd/3rd COMBINATIONS					
4(2)-3-T2-0	40.6	1.8	910	20610	11.2 (T2-GEO)
5(2)-3-T2-0	47.6	2.9	840	13950	10.0 (T2-GEO)
✓ 5(2)-2-T2-0	49.7	3.5	760	10730	9.4 (T2-GEO)
5(2)-3-1-0	(T/W = 1.1 AT LIFTOFF WITH NO PAYLOAD OR SHROUD)				
3(2)-2-T2-0	34.6	1.1	920	-	

✓ RETAIN FOR BEST 4TH STAGE VEHICLE

Table 3.3-20. Class B Four-Stage Vehicles

• BEST FOURTH STAGE (WITH GOOD 3 STG VEHICLE)

OPTION	PAYLOAD (K LBS)		COST ($/LB)		OTHER FACTORS
	LEO	GEO	LEO	GEO	MAX G
* 4(2)-2-C-0	40.8	5.5	930	6,930	9.7
* 4(2)-2-C-TT	44.5	4.9	1,080	9,890	8.1
4(2)-2-C-IUS	44.8	4.4	1,520	15,510	7.9
4(2)-2-C-C	58.7	11.3	870	4,500	7.4 } DOES NOT REFLECT PROPER SHROUD PENALTY
4(2)-2-C-WBC	65.8	12.9	900	4,580	6.7 }
4(2)-2-C-S3	52.1	6.6	780	6,080	26.9 TOO HOT

• OTHER 2ND/3RD/4TH STAGES COMBINATIONS

OPTION	PAYLOAD LEO	PAYLOAD GEO	COST LEO	COST GEO	MAX G
4(2)-4-C-TT	46.0	4.7	1,130	11,100	11.3
* 4(2)-2-T2-C	60.9	11.7	790	4,110	6.2
4(2)-3-T2-C	60.5	11.3	830	4,430	6.4
* 4(2)-4-T2-C	65.0	12.0	800	4,320	9.1
* 4(2)-4-1-C	70.1	11.1	760	4,770	7.4

* SELECTION FOR INDICATED PARAMETER

Table 3.3-21. *Class B Four-Stage Vehicles (Continued)*

SRB-X-68

- BEST FIRST STAGE (WITH GOOD 2, 3, 4 STAGE COMBINATIONS)

	PAYLOAD (K LBS)		COST/LB		OTHER FACTORS
OPTION	LEO	GEO	LEO	GEO	MAX G
4(2)-2-T2-C	60.9	11.7	790	4110	6.2
✓ 5(2)-2-T2-C	69.3	13.3	740	3830	6.1
✓ 4(2)-4-T2-C	65.0	12.0	800	4320	9.1
5(2)-4-T2-C	(LIFTOFF T/W = 1.1 WITH NO PAYLOAD OR SHROUD)				
4(2)-4-1-C	70.1	11.1	760	4770	7.4
✓ 5(2)-4-1-C	(LIFT-OFF T/W = 1.03 WITH NO PAYLOAD OR SHROUD)				
3(2)-2-T2-C	52.1	9.9	850	4550	
OTHER COMBINATIONS					
✓ 5(2)-3-T2-C	68.7	12.8	770	4130	6.4
5(2)-3-1-C	(LIFT-OFF T/W = 1.1 WITH NO PAYLOAD OR SHROUD)				

✓ RETAIN FOR FURTHER COMPARISON

Table 3.3-22. Class B Summary

VEHICLE/CONCEPT	PAYLOAD (K LBS)		COST/LB		MAX G	SRM MODIFICATION		
	LEO	GEO	LEO	GEO		MIN	MOD	EXT
● 3 STAGE VEHICLES								
✓ 4(2)-2-C-0	40.8	5.5	930	6930	9.7	-	-	1
✓ 4(2)-4-C-0	40.6	5.0	1030	8390	13.0	-	1	-
✓ 4(2)-2-T2-0	42.3	2.4	830	14800	10.5(T2)	-	-	1
4(2)-4-T2-0	44.0	2.2	890	17250	10.7	-	1	0
5(2)-2-T2-0	49.7	3.5	760	107300	9.4(T2)	1	-	1
✓ 5(2)-3-C-0	44.3	5.6	970	7610	9.3	1	1	-
5(2)-2-C-0	47.6	6.5	860	6270	9.6	1	-	1
● 4 STAGE VEHICLES								
4(2)-2-C-TT	44.5	4.9	1080	9890	8.1	-	-	1
4(2)-2-T2-C	60.9	11.7	790	4110	6.2	-	-	1
✓ 4(2)-4-T2-C	65.0	12.0	800	4320	9.1	-	1	-
✓ 4(2)4-1-C	70.1	11.1	760	4770	7.4	-	1	1
5(2)-2-T2-C	69.3	13.3	740	3830	6.1	1	-	1
✓ 5(2)-3-T2-C	68.7	12.8	770	4130	6.4	1	1	-

✓ BEST CONCEPTS

3.3.4.3 Conclusions and Recommendations

The conclusions and observations resulting from the class B analysis are presented in table 3.3-23. Five concepts are recommended for further consideration, as shown in table 3.3-24.

3.3.5 Class C Vehicle Results

This particular class of vehicle appeared to have the least amount of interest partly because other SDV concepts were more adapted to providing such large payload capability. Accordingly, this class received the least amount of analysis. A list of some investigated concepts is in table 3.3-25. It can be observed that three-stage vehicles of this class do not come close to satisfying the LEO target of 95,000 lb or the GEO target of 17,000 lb; a number of four-stage concepts satisfied both targets. It was recommended that class C vehicles not be investigated further at this time because: (1) other SDV's, such as those using LO_2/LH_2 in the lower stages, offer better capability; (2) there is very little evidence of relatively near-term payload requiring this much mass; and (3) the three parallel-burn first-stage boosters would press the limit of KSC launch platforms and be incompatible with those available at VAFB.

3.3.6 Summary and Recommendations

Some of the more interesting concepts for each vehicle class are summarized in table 3.3-26 to enable a class-to-class comparison. The observations made from these data are as follows:

a. Titan strapons make class A competitive with class B and offer the potential for using Titan facilities.

b. Vehicle core (selected second, third, and fourth stages) could be common between class A and class B.

c. Class C vehicles offer considerable payload but approach facility modification feasibility limits—no additional effort warranted.

The recommendations from the first screening are as follows:

a. Pursue both class A and class B vehicles as indicated in their respective sections.

b. Strapon class A versus class B is key trade.

c. SRM second stage for both classes requires further investigation.

    1. One segment versus two segment for class A.
    2. Two segment versus four segment for class B.

Table 3.3-23. Conclusions and Observations

- 3 STAGE VEHICLES DO NOT SATISFY PERFORMANCE TARGETS FOR THIS CLASS
- 4 STAGE VEHICLES SATISFY TARGETS AND STS PERFORMANCE
- "GOOD" VEHICLE: 4 SEG BOOSTERS; 2 SEG SRM; TITAN 2ND STAGE; D-IT CENTAUR
  - COULD OPERATE AS A THREE OR FOUR STAGE VEHICLE
- OBSERVATIONS:
  - TITAN 2ND STAGE GOOD MATCH IN STACK
    - WITH RESTART — BETTER LEO PERFORMANCE THAN CENTAUR
  - 2 SEG 2ND STAGE PROVIDES COMPARABLE PERFORMANCE WITH 4 SEG AND HAS SHORTER STACK (BY 50 FEET!)
    - CONFIGURATION GEOMETRY IS A CHALLENGE
  - 5 SEG BOOSTERS OFFER PERFORMANCE GROWTH

Table 3.3-24. Recommended Class B Concepts

FAMILY	CONFIGURATION CODE	APPLICATION ▷	RATIONALE FOR CONTINUED INVESTIGATION
1	4(2)-2-C 4(2)-4-C	P, L, G P, L, G	• 2 VERSUS 4 SEG 2ND STAGE • REF CONFIG – MSFC CONFIG 6
2	4(2)-4-T2-0 4(2)-4-T2-0	P L, G	• 2 VERSUS 4 SEG TRADE • NON CRYO LEO/POLAR
3	4(2)-2-T2-0 4(2)-2-T2-0	P L, G	• EVOLUTION FROM CLASS A FAMILY 3 AND LESS HEIGHT THAN CLASS B FAMILY 3
4	4(2)-4-1-0 4(2)-4-1-0	P L, G	• ALL NASA VEHICLE • (MAY NEED LIQUID INSERTION STAGE FOR LEO)
5	3(2)-2-T2-0 3(2)-2-T2-0	P L, G	• LESS GLOW THAN FAMILY 3 AND LESS COST PER FLIGHT

▷ P – POLAR, L – LEO, G – GEO

Table 3.3-25. Class C Vehicles

• 3 STAGE VEHICLES

OPTION	PAYLOAD (K LBS)		COST/LB		MAX G	GLOW
	LEO	GEO	LEO	GEO		10^6 LB
* 5(3)-4-T2-0	67.3	5.4	750	9280	10.9 (4) 7.9 (1)	6.0
4(3)-5-1-0	59.9	< 0	780	—	6.4	6.0

• 4 STAGE VEHICLES

4(3)-5-1-WBC	102.8	18.3	660	3720	5.9 IN 3RD	5.8
4(3)-4-1-WBC	97.1	17.3	680	3820	6.0 IN 3RD	5.5
5(3)-3-S1-WBC	95.4	18.4	700	3610	6.8 IN 2ND	5.8
5(3)-3-T2-WBC	94.4	18.2	740	3810	7.7 IN 2ND	5.8
4(3)-5-T2-WBC	93.2	17.8	740	3890	7.8 IN 2ND	5.5
4(3)-5-1-C	92.3	14.6	650	4120	7.1 IN 3RD	5.8
* 5(3)-4-T2-C	92.0	17.0	690	3810	8.9 IN 2ND	6.1
* 5(3)-4-1-C	99.7	15.7	630	3980	7.1 IN 3RD	6.4
* 4(3)-5-T2-WBC	105.0	20.0				

* MOST PROMISING

Table 3.3-26. *Vehicle Class Payload Comparison*

SRB-X-79

PAYLOAD IN KLBS [1]

	CLASS A			CLASS B			CLASS C		
	CONCEPT	LEO	GEO	CONCEPT	LEO	GEO	CONCEPT	LEO	GEO
● 3 STAGE	0-4-1-C-0	27	3	4(2)-2-C-0	41	6	5(3)-4-T2-0	67	6
	T05-4-1-C-0	41	6	(5)(2)-2-C-0	48	7			
	T07-4-1-C-0	46	7						
	0-4-1-T2-0	29	-						
● 4 STAGE	0-4-1-T2-C	40	8	4(2)-2-T2-C	61	12	5(3)-4-T2-C	92	17
	T05-4-1-T2-C	58	11				5(3)-4-1-C	100	16
● 3/4 STAGE COMBINATION	0-4-2-T2-0	29	-	4(2)-2-T2-0	42	-			
	0-4-2-T2-C	45	9	4(2)-2-T2-C	61	12			
	0-4-1-T2-0	25	-						
	0-4-1-T2-C	40	8						
● MAXIMUM	1(4)-4-2-T2-WBC	78	16	4(2)-5-1-WBC	84	15	4(3)-5-T2-WBC	105	20

[1] VALUES ARE ROUNDED TO NEAREST THOUSAND

d. Compare Titan second stage, Centaur, and MX first stage for SRB-X third-stage application.

e. Maintain MSFC configurations 3 and 6 as references.

f. If possible, develop evolutionary story of class A to class B (e.g., strapons, common upper stage core).

g. No further assessment of widebody Centaur since payload target can be met with standard D-IT.

3.4 SECOND SCREENING ANALYSES

A second screening analysis was initiated to further reduce the number of options and to address factors resulting from review of the first screening. These factors included the following. First, consideration of several new stage options: the Titan first stage as SRB-X stage 2 and the Delta second stage for SRB-X stage 3. Secondly, reconsideration of a derivative of the MX first stage for SRB-X stage 3 application. This was the result of the concern associated with the phaseout of the Titan vehicle. Finally, evaluation of the options for the condition of the STS SRM and derivatives using steel rather than filament wound cases. This factor was the result of the uncertainty at this point in time regarding the reusability and cost of the FWC. This particular analysis was accomplished using two separate steps.

3.4.1 Preliminary Assessment

As a result of the first FWC coarse screening, 10 launch vehicle configuration families were recommended for further analysis. Consideration of the stage options mentioned above increased this number to 12.

Stage and vehicle element characteristics used in the preliminary assessment are shown in tables 3.4-1 and -2. Again, inerts for the STS SRM derivatives reflect steel cases. The other change relative to the characteristics used in the first screening is that shroud weights have been changed against fourth as well as third stages.

Vehicle level performance and other characteristics associated with the candidate configurations are shown in tables 3.4-3 and -4. These data led to the conclusion that four vehicle families and one individual configuration should be dropped from any further assessment. These include the following:

Family	Configuration	Rationale
A1	T05-4-1-C	Other strapon configurations offer better performance and equivalent facility impact.

Table 3.4-1. Class A Vehicle and Stage Characteristics [3]

APPLIC.	STAGE NAME	STAGE CODE NUMBER	WEIGHTS PROP	WEIGHTS INERT & SUBSYS	WEIGHTS INTER STAGE	WEIGHTS INERT EXPEND.	PERFORMANCE VAC THR	PERFORMANCE ISP	PERFORMANCE BURN TIME	PERFORMANCE EXP RATIO	PERFORMANCE THROAT AREA	UNIT COST	SHROUD WEIGHTS FIXED	SHROUD WEIGHTS PER LB P/L
STRAPONS	SRB 2X1 ST	A 0 1	628000	153200	0	0	2900000	277	60.0	13.6	2450.8	9000000	0	0
	T 0TH 5SEG	A 0 2	850000	167800	0	0	2354000	266	96.05	10.0	1832.2	15000000	0	0
STAGE 1	SRB 1X4 ST	A 1 1	1107000	184100	5000	0	2850000	267.2	125.6	7.72	1987.1	7000000	0	0
STAGE 2	SRB 1X1 ST	A 2 1	314000	60300	2500	0	717280	285.2	125	28.3	543.3	9000000	0	0
	SRB 1X2 ST	A 2 2	586000	87800	2500	0	1298600	277	125	14.8	1034.9	11000000	0	0
	[1] T 1ST	A 2 5	288649	17686	0	0	529000	301.4	200	10	300	10000000	0	0
STAGE 3	CENT D1-T	A 3 1	30000	4850	1500	275	30000	444	444	57	43.0	13000000	4900	.12
	TIT34D 2ND	A 3 3	66380	7250	1500	50	100864	316	208	35.4	93.1	10000000	2350	.12
	S-1	A 3 5	96000	9000	1500	100	522400	283	52	10.0	1103	7000000	2350	.12
	[2] D 2ND X 4	A 3 7	51476	7140	1500		39400	314	410	65	44.4	1000000	2350	.12
STAGE 4	CENT D1-T	A 4 3	30000	4850	0	275	30000	444	444	57	43.0	13000000	5500	.12
	D 2ND X4	A 4 6	51476	7140	0	0	39400	314	410.2	65	44.4	10000000	2350	.12

$

[1] TITAN FIRST STAGE
[2] DELTA SECOND STAGE
[3] STS SRM'S USE STEEL CASES

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Table 3.4-2. Class B Vehicle and Stage Characteristics [3]

APPLIC	STAGE NAME	STAGE CODE NUMBER	WEIGHTS PROP	WEIGHTS INERT & SUBSYS	WEIGHTS INTER STAGE	WEIGHTS INERT EXPEND.	VAC THR	PERFORMANCE ISP	PERFORMANCE BURN TIME	PERFORMANCE EXP RATIO	PERFORMANCE THROAT AREA	UNIT COST	SHROUD WEIGHTS FIXED	SHROUD WEIGHTS PER LB P/L
STAGE 1	SRB 2X2 FU	B 1 4	1172000	208000	0	0	2597200	267.2	[illegible]	14.8	1034.9	8000000	0	0
	SRB 2X3 FU	B 1 1	1669700	271000	0	0	5900000	267.2	111	7.72	3974.2	11000000	0	0
	SRB 2X4 FU	B 1 2	2214000	311400	0	0	5700000	267.2	125.6	7.72	4290.6	14000000	0	0
STAGE 2	SRB 1X2 FU	B 2 1	586000	80500	5000	0	1298600	277.0	125	14.8	1034.9	11000000	0	0
	SRB 1X4 FU	B 2 3	1107000	128100	5000	0	2353000	267.2	125.6	7.72	1987.1	15000000	0	0
	[1] T 1ST	B 2 5	288649	17686	0	0	529000	301.4	200	10	300	10000000	0	0
STAGE 3	CENT D1-T	B 3 1	30000	4850	1500	275	30000	444	444	57	43.0	13000000	4900	.12
	TIT34D 2ND	B 3 3	66380	7200	1500	50	100864	316	208	35.4	93.1	10000000	2350	.12
	SRB 1X1 FU	B 3 6	314000	51120	2500	0	717280	285.2	125	28.3	543.3	9000000	2350	.24
	[2] D2ND X 4	B 3 8	51426	7140	1500	0	39400	314	410	65	44.4	1,000,000	2350	.12
STAGE 4	CENT D1-T	B 4 3	30000	4850	0	275	30000	444	444	57	43.0	13000000	5500	.12
	D 2ND X 3	B 4 6	39705	5802	1000	0	28300	319	447.6	60	44.4	10000000	2350	.12
	T34D 2ND	B 4 7	66380	7250	1500	50	100864	316	208	35.4	93.1	10000000	2350	.12

$

[1] TITAN FIRST STAGE

[2] DELTA SECOND STAGE

[3] STS SRM'S USE STEEL CASES

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Table 3.4-3. SRB-X Class A Vehicle Summary

• STEEL CASE STS SRM'S

FAMILY	CONFIGURATION CODE	PAYLOAD (K LBS)			GLOW (M LBS)	MAX G'S (STAGE)	APPROX. HT (FT)
		LEO	POLAR	GEO			
A1	0-4-1-C-0 T05-4-1-C-0	24.6 38.1	20.2 31.2	2.8 5.3	1.7 2.8	5.7 (2ND) 5.2 (2ND)	280
A2	0-4-1-T2-0 0-4-1-T2-C	23.0 37.1	18.2 31.2	< 0.0 6.7	1.8 4.8	4.5 (2ND) 4.1 (1ST)	280
A3	0-4-2-T2-0 0-4-2-T2-D2(4) 0-4-2-T2-C	26.2 ~33.2 41.7	20.7 27.0 35.0	0.2 1.3 7.6	2.1 2.1 2.1	6.9 (2ND) 5.0 (2ND) 6.0 (2ND)	305
A4	T05-4-1-T2-0 T04-4-1-T2-C	37.7 53.9	30.2 45.3	— 10.3	2.8 2.8	4.1 (1ST) 4.1 (1ST)	280
A5	1(2)-4-1-T2-0 1(2)-4-1-T2-C	34.8 50.4	27.8 42.4	1.2 9.6	2.6 2.6	4.2 (1ST) 4.1 (1ST)	280
A6	0-4-T1-D2(4)-0 0-4-T1-C-0	30.9 37.8	25.0 31.8	1.0 6.7	1.7 1.7	5.0 (2ND) 8.1 (2ND)	240

Table 3.4-4. SRB-X Class B Vehicle Summary

• STEEL CASE STS SRM'S

FAMILY	CONFIGURATION CODE	PAYLOAD (K LBS)			GLOW (M LBS)	MAX G'S (STAGE)	APPROX HT (FT)
		LEO	POLAR	GEO			
B1	0-4(2)-2-C-0	35.8	29.0	4.5	3.4	7.5 (2ND)	
	0-4(2)-4-C-0	33.1	26.5	3.7	3.9	10.7 (2ND)	
B2	0-4(2)-4-T2-0	36.0	28.3	0.8	4.0	8.5 (2ND)	
	0-4(2)-4-T2-C	56.6	47.0	10.2	4.0	7.9 (2ND)	
B3	0-4(2)-2-T2-0	36.9	29.3	1.3	3.4	6.2 (2ND)	
	0-4(2)-2-T2-C	55.2	46.1	10.3	3.4	5.7 (2ND)	
B4	0-3(2)-2-T2-0	30.5	24.1	0.3	2.8	6.3 (2ND)	
	0-3(2)-2T2-D2(4)	~39.0	31.9	~3.0	2.8	5.0 (1ST)	
	0-3(2)-2-T2-C	47.6	39.9	8.8	2.8	5.8 (2ND)	
B5	0-4(2)-4-1-0	21.3	8.1	< 0.0	4.3	10.5 (2ND)	
	0-4(2)-4-1-C	61.1	49.9	9.2	4.3	6.9 (3RD)	
B6	0-4(2)-2-S1-0	36.6	28.6	< 0.0	3.4	13.9 (3RD)	
	0-4(2)-2-S1-C	55.8	46.7	~10.3	3.4	9.6 (3RD)	

A2	4-1-T2-0 4-1-T2-C	Performance no better than A3; does not provide evolution to class B vehicles.
A5	1(2)-4-1-T2-0 1(2)-4-1-T2-C	Inferior to A4.
B5	4(2)-4-1-0 4(2)-4-1-C	Insufficient polar performance with three stages. Primary reason is high inert weight of stage 3.
B7	3(2)-T1-T2-0 3(2)-T1-T2-C	Reasonable payload; structural integrity not assessed but is very suspect.

3.4.2 Final Assessment

The nine remaining configurations are indicated in table 3.4-5. The performance analysis of these configurations relative to the first screening involved the following adjustments: (1) jettisoning of shroud at 1 psf rather than at end of second-stage burn, (2) use of a coast maneuver after second-stage burn, and (3) more optimum launch trajectories (velocity requirements) as a result of POST runs. In terms of stage characteristics, it was also decided to determine performance for STS SRM's using both steel and FW cases. Characteristics of candidate stages involving steel SRM's were previously shown in tables 3.4-1 and -2. An equivalent set of data, except for the use of FWC SRM, is presented in tables 3.4-6 and -7. A final performance adjustment revised payload requirements to relate to time periods rather than to classes of vehicles. In addition, if possible, it would be desirable to satisfy polar requirements with three-stage vehicles due to height considerations. The revised viewpoint on requirements is follows.

	Payload (1000 lb)	
Revised performance requirements	1987-90	1991-95
Steel cases if possible		
Three stages for LEO and polar	40 and 30	45 and 35
Four stages for GEO	8	12

Table 3.4-5. *Leading Candidates for Second Screening*

CODE	LAUNCH VEHICLE	COMMENT
A1	0-4-1-C-0	• REF. CLASS A VEHICLE • ONE VEHICLE ALL APPLICATIONS
A3	0-4-2-T2 [1]	• BEST OF 1 VS 2 SEG 2ND STG OPTIONS • NON CRYO FOR POLAR
A4	T05-4-1-T2 [1]	• BEST STRAP-ON VEHICLE • NON CRYO FOR POLAR
A6	0-4-2-S1 [1]	• ALTERNATE 3RD STAGE • NON CRYO FOR POLAR
B1	0-4(2)-2-C-0	• REF. CLASS B VEHICLE • ONE VEHICLE ALL APPLICATIONS
B2	0-4(2)-4-T2 [1]	• 4 VS 2 SEG 2ND STAGE • NON CRYO FOR POLAR
B3	0-4(2)-2-T2 [1]	
B4	0-3(2)-2-T2 [1]	• ALTERNATE FIRST STAGE • POTENTIALLY BEST VEHICLE FOR JOINT WTR/ETR APPLICATION
B6	0-4(2)-2-S1 [1]	• ALTERNATE 3RD STG, NON CRYO

[1] WOULD USE CENTAUR D1-T FOR GEO

Table 3.4-6. Class A Vehicle and Stage Characteristics [1]

APPLIC	----STAGE---- NAME	CODE NUMBER	PROP	------UEIGHTS------ INERT & SUBSYS	INTER STAGE	INERT EXPEND.	UAC THR	------PERFORMANCE------ ISP	BURN TIME	EXP RATIO	THROAT AREA	UNIT COST	SHROUD UEIGHTS FIXED	PER LB P/L
STRAPONS	SRB 2X1 FU	A 0 1	628000	138480	0	0	2900000	277	60.0	13.6	2450.8	9000000	0	0
	T 0TH 5SEG	A 0 2	850000	167800	0	0	2354000	266	96.05	10.0	1832.2	15000000	0	0
STAGE 1	SRB 1X4 FU	A 1 1	1107000	146300	5000	0	2850000	267.2	125.6	7.72	1987.1	7000000	0	0
STAGE 2	SRB 1X1 FU	A 2 1	314000	52920	2500	0	717280	285.2	125	28.3	543.3	9000000	0	0
	SRB 1X2 FU	A 2 2	586000	74500	2500	0	1298600	277	125	14.8	1034.9	11000000	0	0
	[2] T 1ST	A 2 5	288649	17686	0	0	529000	301.4	200	10	390	10000000	0	0
STAGE 3	CENT D1-T	A 3 1	30000	4850	1500	275	30000	444	444	57	43.0	13000000	4900	.12
	TIT34D 2ND	A 3 3	66380	7250	1500	50	100864	316	208	35.4	93.1	10000000	2350	.12
	[3] D 2ND X 4	A 3 7	51476	7140	1500	0	39400	314	410	65	44.4	10000000	2350	.12
STAGE 4	-NULL 4TH-	A 4 0	0	0	0	0	0		0.00001	0	0	0	0	0
	CENT D1-T	A 4 3	30000	4850	0	275	30000	444	444	57	43.0	13000000	5500	.12
	D 2ND X 4	A 4 6	51476	7140	0	0	39400	314	410	65	44.4	10000000	2350	.12

$

[1] STS SRM DERIVATIVES USE FWC

[2] TITAN FIRST STAGE

[3] DELTA SECOND STAGE

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Table 3.4-7. Class B Vehicle and Stage Characteristics [1]

APPLIC	STAGE NAME	STAGE CODE NUMBER	WEIGHTS PROP	WEIGHTS INERT & SUBSYS	WEIGHTS INTER STAGE	WEIGHTS INERT EXPEND.	PERFORMANCE VAC THR	PERFORMANCE ISP	PERFORMANCE BURN TIME	PERFORMANCE EXP RATIO	PERFORMANCE THROAT AREA	UNIT COST	SHROUD WEIGHTS FIXED	SHROUD WEIGHTS PER LB P/L
STAGE 1	SRB 2X2 ST	B 1 4	1172000	234400	0	0	2597200	267.2	125	14.8	1034.9	8000000	0	0
	SRB 2X3 ST	B 1 1	1669700	323200	0	0	5900000	267.2	111	7.72	3974.2	11000000	0	0
	SRB 2X4 ST	B 1 2	2214000	382200	0	0	5700000	267.2	125.6	7.72	4290.6	14000000	0	0
STAGE 2	SRB 1X2 ST	B 2 1	586000	93700	5000	0	1298600	277.0	125	14.8	1034.9	11000000	0	0
	SRB 1X4 ST	B 2 3	1107000	163500	5000	0	2353000	267.2	125.6	7.72	1987.1	15000060	0	0
	[2] T 1ST	B 2 5	288649	17656	0	0	529000	301.4	200	10	300	10000000	0	0
STAGE 3	CENT D1-T	B 3 1	30000	4850	1500	275	30000	444	444	57	43.0	13000000	4900	.12
	TIT34D 2ND	B 3 3	66380	7260	1500	50	100864	316	208	35.4	93.1	10000000	2350	.12
	SRB 1X1 ST	B 3 6	314000	60300	2500	0	717280	285.2	125	28.3	543.3	9000000	2350	.12
	S-1	B 3 5	96000	9000	1500	100	522400	283	52	10.0	1103	7000000	2350	.12
	[3] D 2ND X 4	B 3 8	51476	7140	1500	0	39400	314	410	65	44	10,000,000	0	0
STAGE 4	CENT D1-T	B 4 3	30000	4850	6	275	30000	444	444	57	43.0	13000000	5500	.12
	T34D 2ND	B 4 7	66330	7250	1500	50	100864	316	208	35.4	93.1	19000000	2350	.12
	D 2ND X4	B 4 8	51476	7140	1500	0	39400	314	410.2	65	44.4	10000000	2350	.12

$

[1] STS SRM DERIVATIVE USE FWC

[2] TITAN FIRST STAGE

[3] DELTA SECOND STAGE

The results for LEO, polar, and GEO missions are indicated in figures 3.4-1, -2, and -3, respectively. The charts are formatted to indicate the performance if steel cases are used and the incremental increases in payloads should all STS SRM's within a vehicle use FWC's. From a performance standpoint, the assessment of these configurations is presented in table 3.4-8. Six configurations are judged to merit further examination.

The principal characteristics of these configurations are summarized in figure 3.4-4. The first configuration listed under each vehicle is that used for polar; the second is for GEO mission. In all cases, the first two stages use SRB's. The third stage is the Titan core second stage (T2) in all configurations except B6. In this configuration, the third stage is similar to the MX first stage (S1). The A3 vehicle is a pure class A type vehicle. To satisfy the polar performance, a storable fourth stage was necessary in the form of the D2 (Delta core stage 2—a cluster of four units). The A4 configuration employs the use of two Titan 5-1/2 segment strapons. The B2 and B3 vehicles show the influence of different second stages; and B6, the impact of using a different third stage. Configuration B4 illustrates the height advantage resulting from using three-segment rather than four-segment first-stage SRB's. Payload capability for the vehicles when using steel cases is at least 30,000 lb to polar and 9000 lb to GEO. A significant difference does exist in terms of height and GLOW. At this point, only the B4 configuration fits within the current STS facility constraints at WTR and ETR (hook height of 198 ft), although B3 and B6 could be modified to be compatible. Key issues addressed in the third screening are also indicated.

3.5 THIRD SCREENING ANALYSES

This section describes the analyses of the six configurations resulting from the second screening (see fig. 3.4-4) and concludes with the recommendation of a single concept. Analyses were performed only in those areas that would serve to establish technical feasibility of the concepts and/or indicate key differences between concepts that would contribute to the selection of the preferred concept. Technical areas analyzed and key issues are as follows:

a. Propulsion—SRM thrust tailoring and weight and performance update; improved liquid third stage.
b. Structures—Capability of existing systems to sustain SRB-X design conditions.
c. Performance—Update payload capability.
d. Flight control—Ability to follow flightpath and thrust vector control needs.
e. Facilities—STS versus Titan launch sites and extent of modification.
f. Cost—SRM and facility DDT&E.

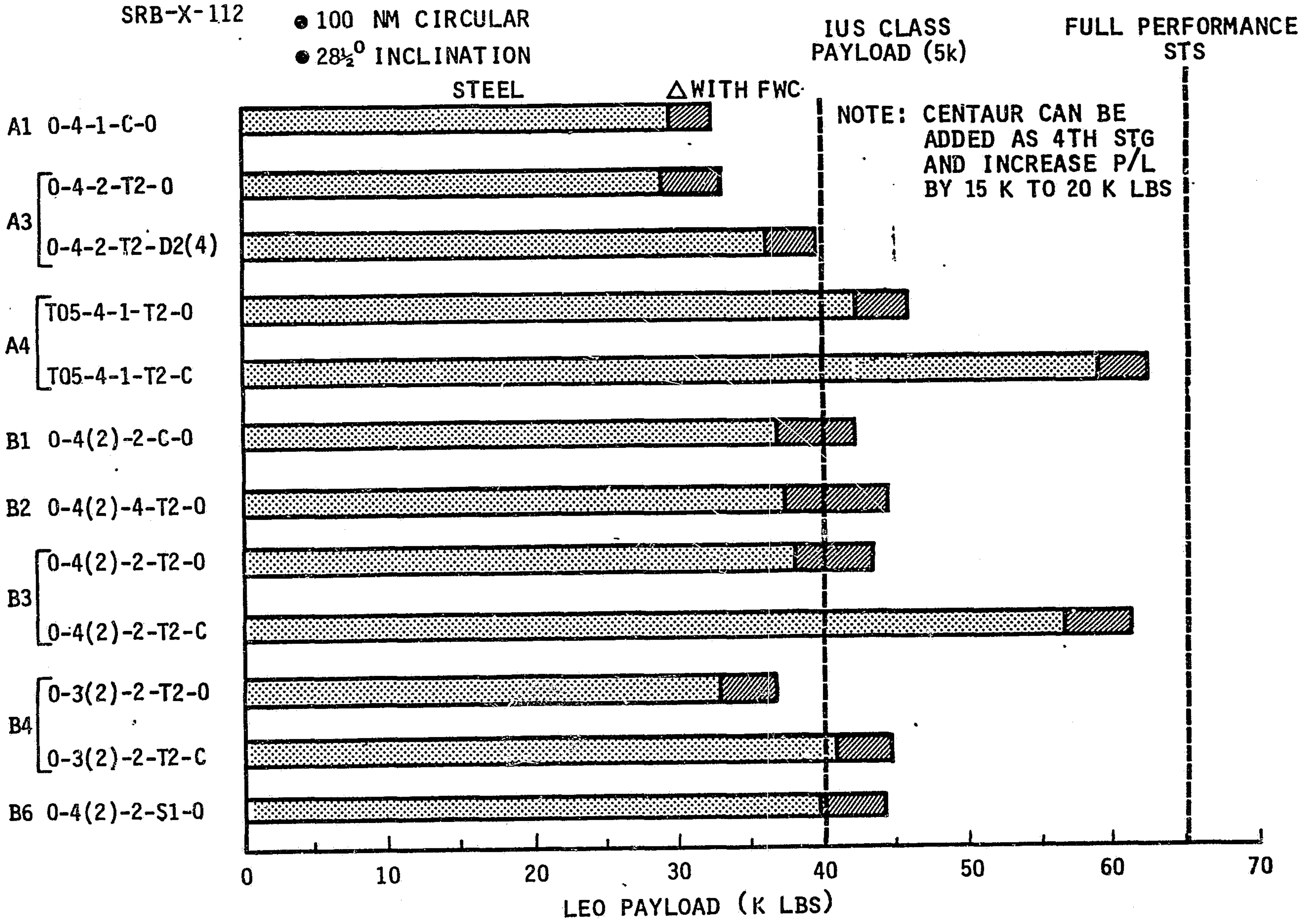


Figure 3.4-1. LEO Performance Comparison

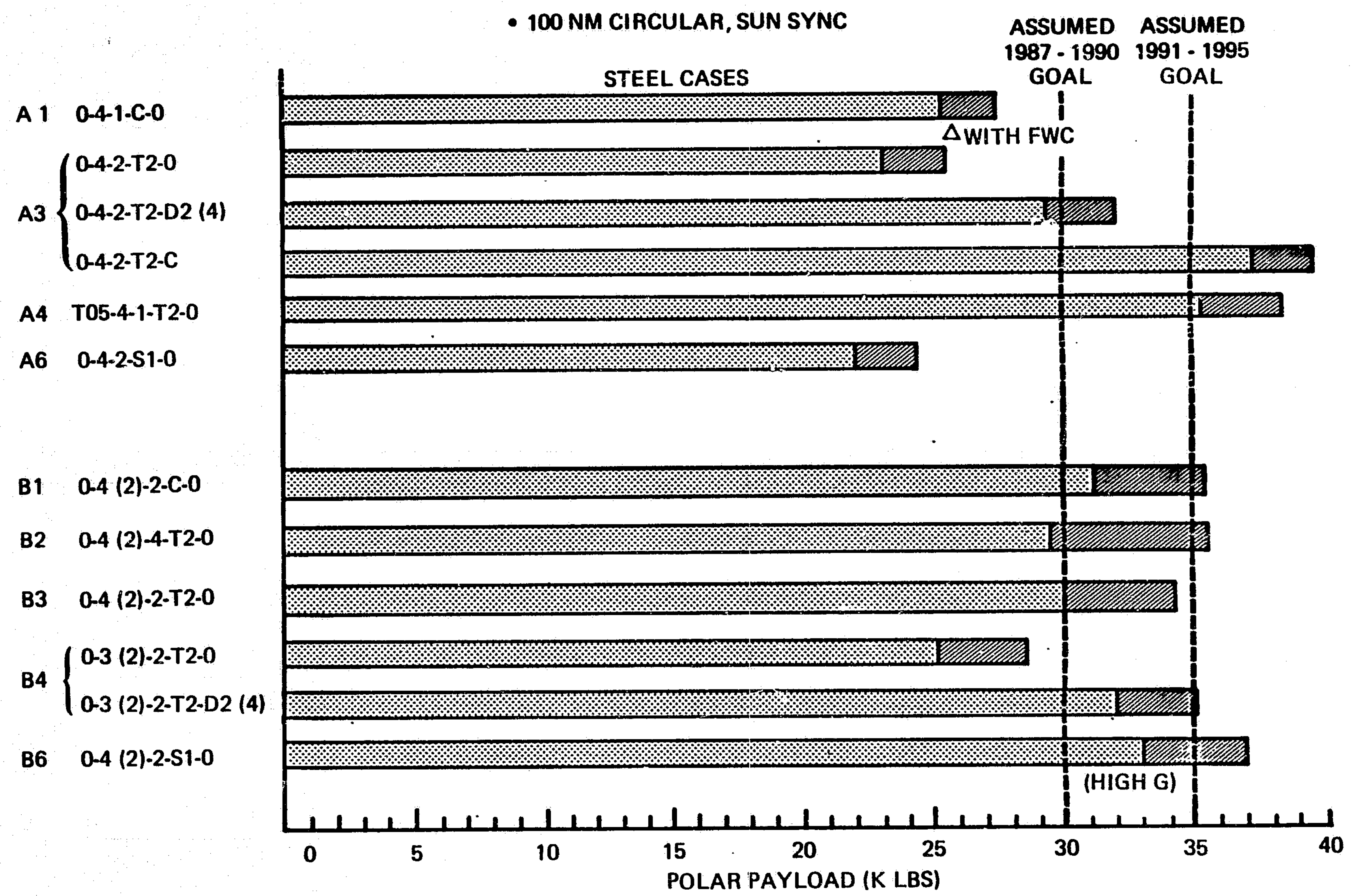


Figure 3.4-2. Polar Pe·formance Comparison

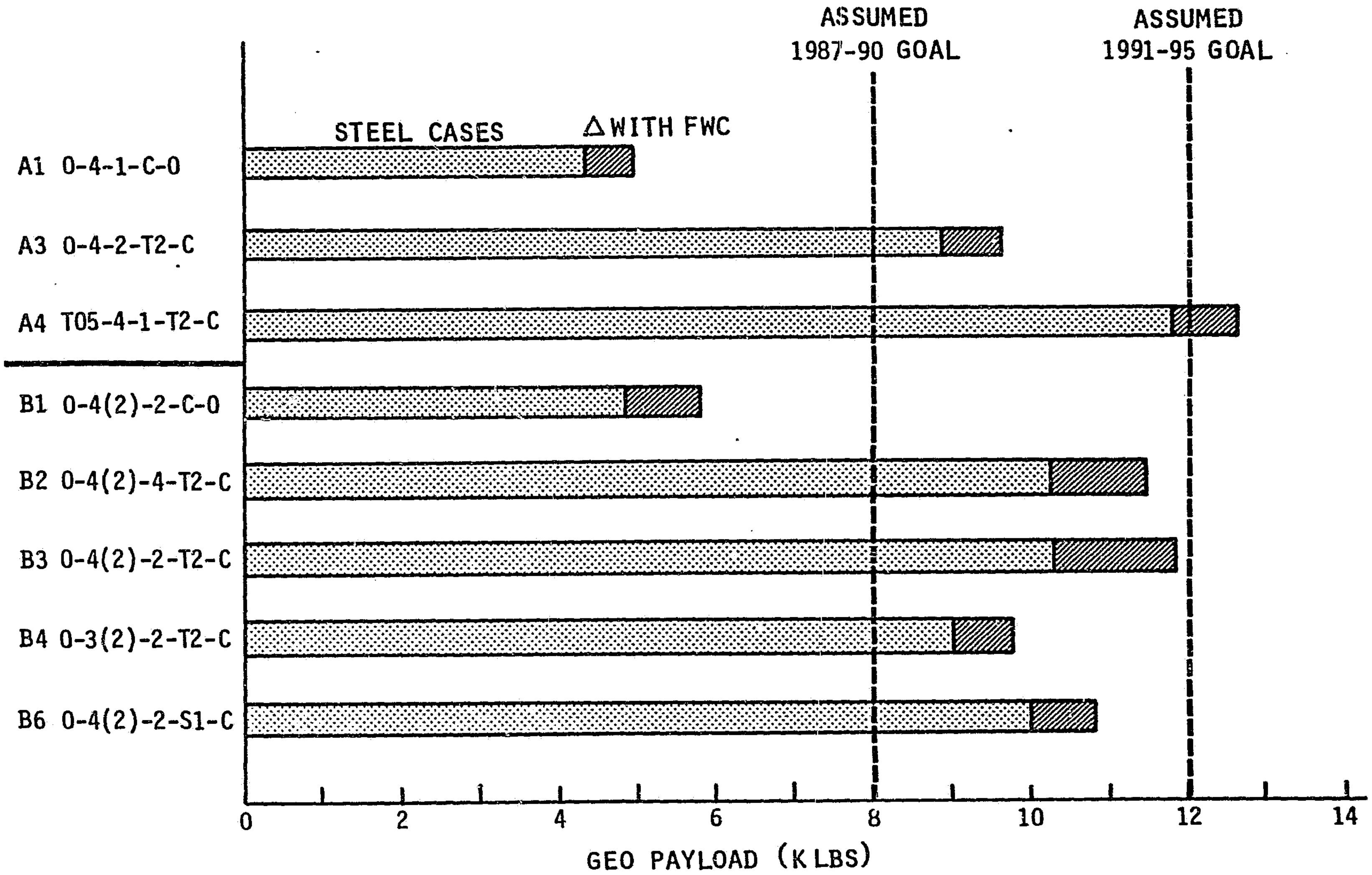


Figure 3.4-3. GEO Performance Comparison

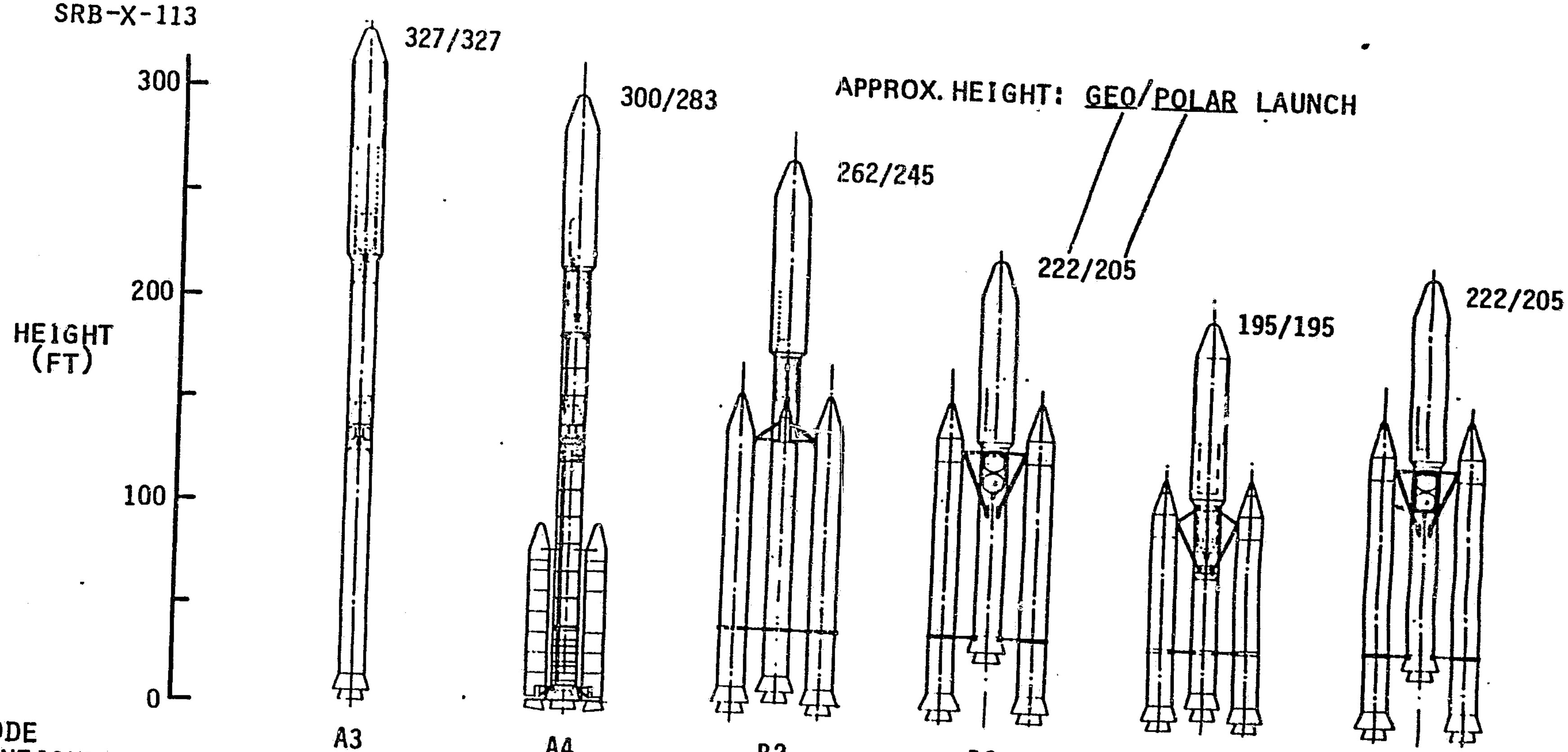
Table 3.4-8. *Performance Assessment*

- DESIRABLE GOAL
  - LEO AND POLAR WITH 3 STAGE
  - GEO WITH 4 STAGE
  - STEEL CASES IF POSSIBLE

  } SATISFY ASSUMED 1987-90 REQ'T

CONFIGURATION	DISPOSITION	COMMENTS
A1 4-1-C	DROP	CANNOT SATISFY REQUIREMENTS EVEN WITH FWC
A3 4-2-T2 [1]	RETAIN	LEO AND POLAR REQUIRES EXTRA TOTAL IMPULSE (E.G., D2 STAGES)
A4 T05-4-1-T2 [1]	RETAIN	SATISFIES ALL MISSIONS WITH STEEL
B1 4(2)-2-C	DROP	CANNOT DO GEO EVEN WITH FWC
B2 4(2)-4-T2 [1]	RETAIN	SATISFIES ALL MISSIONS WITH STEEL
B3 4(2)-2-T2 [1]	RETAIN	SATISFIES ALL MISSION WITH STEEL
B4 3(2)-2-T2 [1]	RETAIN	LEO AND POLAR REQUIRES EXTRA TOTAL IMPULSE (E.G., D2 STAGES)
B6 4(2)-2-S1 [1]	RETAIN	SATISFIES ALL MISSIONS WITH STEEL BUT NEEDS CONSIDERABLE THRUST TAILORING

[1] CENTAUR ADDED FOR GEO MISSIONS



	A3	A4	B2	B3	B4	B6
• CODE	A3	A4	B2	B3	B4	B6
• CONFIGURATION	P 4-2-T2-D2 G 4-2-T2-C	T05-4-1-T2-0 T05-4-1-T2-C	4(2)-4-T2-0 4(2)-4-T2-C	4(2)-2-T2-0 4(2)-2-T2-C	3(2)-2-T2-D2 3(2)-2-T2-C	4(2)-2-S1-0 4(2)-2-S1-C
• PAYLOAD (K LBS) [1] POLAR } STEEL CASES	30	35	30	30	32	33
GEO } STEEL CASES	9	12	10	10	9	10
• GLOW (M LBS)	2.1	2.8	4.0	3.4	2.8	3.4
• KEY ISSUES	• STABILITY • FAC. HT	• FLAME HOLES • FAC. HT	• FAC. HT • G LEVEL • GLOW IMPACT ON XPORTERS	• STRUCT. INTEG. • DEV COST	• DEV COST	• G LEVEL

[1] FOR FWC ADD 1000 TO GEO, 3000 FOR POLAR

P = POLAR; G = GEO

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Figure 3.4-4. Configurations Resulting From Second Screening

The following sections summarize the technical areas and assess the configurations leading to a preferred concept.

3.5.1 Propulsion Characterization

3.5.1.1 SRM Analysis

The configurations investigated during the third screening included the basic STS four-segment SRM and derivatives involving one, two, three, and four segments. One configuration also involved the use of an MX first-stage SRM derivative. A summary of their characteristics is presented in the following paragraph. Further description of each SRM in terms of trades, design concept, and performance features and parametrics is presented in subsequent paragraphs.

Summary. Characteristics of SRM's used in the third screening analysis are summarized in table 3.5.1-1. In most cases, inert weights of the motor cases have been revised from the data available early in the study as a result of further design analysis performed by Thiokol. All derivative SRM's had the goal of maximum use of existing hardware. Specific impulses were also improved for several SRM's as a result of more detailed ballistics analysis and higher expansion ratios. Expansion ratios indicated for one- and two-segment motors were the result of the nozzle being restricted in exit diameter so it would have sufficient clearance within a 146-in-diameter interstage. The expansion ratios for the three-segment SRM operating as a first stage and the four-segment SRM as a second stage were kept the same as the standard four-segment SRM in order to minimize development cost at the expense of a performance penalty. The characteristics of the S1 motor reflect use of the MX first-stage case; however, expansion ratio and grain design are all new.

One-Segment SRM. One-segment SRM designs were analyzed as upper stages. The data that follow relate specifically to configuration A4; however, within indicated constraints, they are applicable to any other SRB-X configuration previously discussed.

The major constraints included (1) restricting the nozzle to a 132-in diameter since it would be enclosed within a 146-in-diameter interstage and (2) a thrust-time profile that would not result in any more than 3.5g's for the vehicle.

Two motor designs were analyzed for the one-segment motor, both meeting the design constraints previously discussed. A comparison of the characteristics is shown in table 3.5.1-2. In each design, the burn rate was lowered as much as possible by tailoring the existing SRM propellant. With burn times of 215 and 185 sec for the two designs, the

Table 3.5.1-1. *SRM Mass and Performance Summary*

SRM	APPLICATION	INERT MASS (K LBS)		PROPELLANT (K LBS)	Isp-VAC (SEC)	BURN TIME (SEC)	$\epsilon_{INITIAL}$
		LW STEEL	FWC [1]				
1 SEGMENT	2ND STAGE	51 *	40 *	320	294 *	185 *	36 *
2 SEGMENT	2ND STAGE	78 *	61 *	610	286 *	186 *	17.6 *
3 SEGMENT	1ST STAGE	118 *	92 *	835	267	130 *	7.72
4 SEGMENT	1ST STAGE	146 *	108 *	1107	267	125	7.72
4 SEGMENT	2ND STAGE	146 *	108 *	1107	267	155	7.72
S1 (MX TYPE)	3RD STAGE	DNA	13 * [2]	196 *	304 *	112 *	50 *

NOTE: NUMBERS HAVE BEEN ROUNDED OFF

[1] REFLECT 0.6 INCH LONGITUDINAL EXPANSION FOR 4 SEGMENT MOTOR AND STEEL DOMES — MASS BASED ON THIOKOL FEASIBILITY STUDIES

[2] KEVLAR CASES AND INCLUDES SUBSYSTEMS

* REFLECTS UPDATED VALUES FOR THIRD SCREENING

Table 3.5.1-2. SRB-X One-Segment SRM Comparisons

Configuration A	Feature	Configuration B
Higher propellant loading (higher web fraction) Allows simplified grain tooling when casting in two half-segments	. Grain design	Maintains similarity with STS-SRM Propellant Grain Design - reduced fin length - 5 fins vs 11 fins - same web fraction May need stress relief modifications
New Nozzle - throat sized for MEOP 1,016 (D_t = 20.9 in)	. Nozzle	New nozzle - throat sized for MEOP 1,016 (D_t = 22.0 in)
Expansion Ratio 39.9	. Expansion Ratio	Expansion Ratio 36.0
	. Performance	
294.1	Isp ($\frac{lbf\text{-}sec}{lbm}$)	293.4
215	Burn time (sec)	185

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motor impulse is delivered without exceeding 3.0g's. Higher performance potential is inherent in the A configuration because of higher propellant loading and delivered Isp. Nevertheless, configuration B was chosen for trajectory work because its propellant grain design is closer to that of the STS SRM.

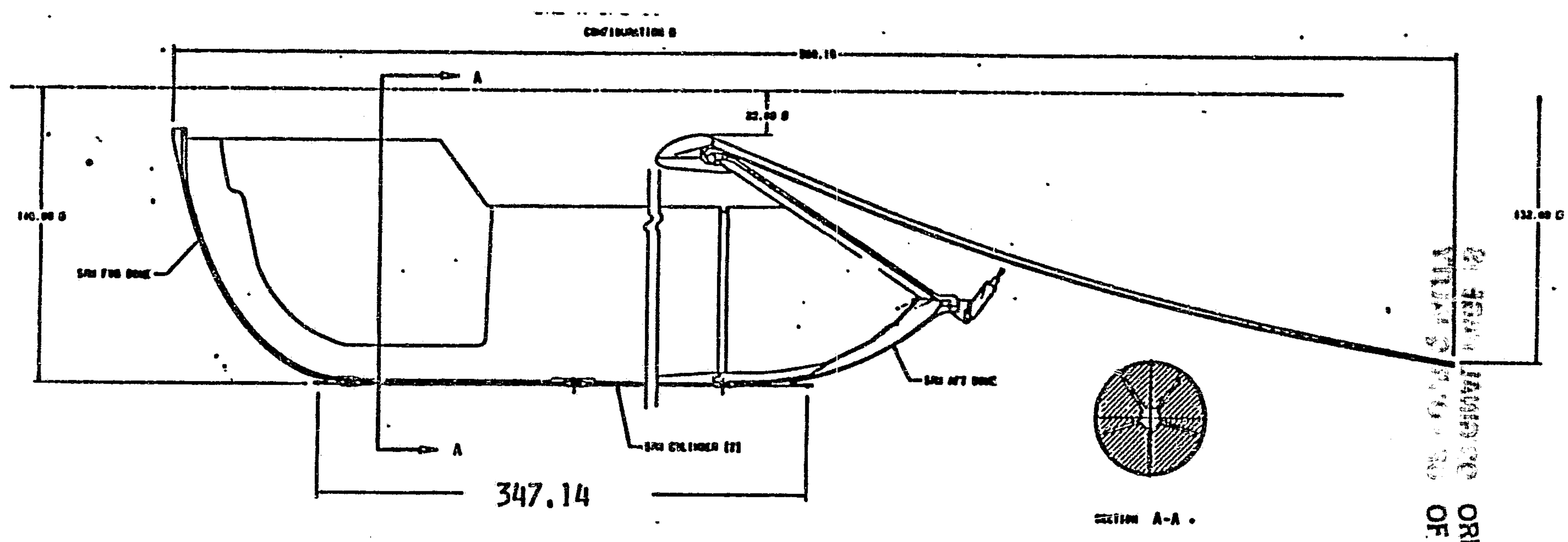
The configuration B one-segment SRM design is shown in figure 3.5.1-1. This approach uses the forward casting segment case sections and the aft dome from the STS SRM. The new nozzle design has a $D_t = 22.0$ in and a $D_{NEP} = 132$ in, resulting in an initial expansion ratio of 36. Propellant grain casting will load the forward segment with similar tooling to the present STS SRM. The number of slots is reduced to five for this design and the slot length is reduced by 101 in. The aft dome will be cast separately. Pressure-time and thrust-time histories are shown for the configuration B one-segment motor in figure 3.5.1-2. These data satisfy limits on MEOP and keep vehicle acceleration substantially below 3.0g's. Better performance was potentially available by optimizing the thrust profile.

Two-Segment SRM. Several promising SRB-X designs used two-segment SRM's for the vehicle's second stage, including configurations A3, B3, B4, and B6. The constraints were the same as for the one-segment SRM regarding g level and nozzle diameter. A larger nozzle diameter is possible for the B configuration since it is not surrounded by an interstage; however, this investigation was delayed until a later date.

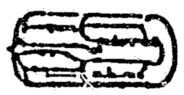
The two-segment SRM concept shown in figure 3.5.1-3 uses case sections from a forward segment, a center segment, and the aft dome of the STS SRM. For a non-recoverable stage, the heavier stiffener case sections of an aft segment are not required since water impact is not a design factor, and the external tank (ET) attach section is not needed for the strut arrangement of configurations B3 and B6. Thrust tailoring was defined to keep vehicle accelerations below 3.0g's. Propellant burn rate was reduced to 0.28 in/sec resulting in a motor burn time of 186 sec. Propellant grain design is similar to that for the STS SRM, but the length of the elevon slots in the forward segment is reduced by 101 in and inhibitors are removed from the ends of the grain.

Baseline performance for this motor was based on an initial expansion ratio of 18 which was established because of a 132-in-diameter limit for the exit cone. Thrust and pressure time history for the SRM is presented in figure 3.5.1-4.

Three-Segment SRM. The three-segment SRM was used as a first stage for configuration B4. The basic configuration was obtained by removing one of the center segments from the standard four-segment SRM. Several options were considered



STS-SRM Common Components



Fwd Segment Case

Aft Dome

MOTOR SUMMARY - CONFIGURATION B

Propellant Weight	319,555 lbm
Inert Weight	50,557 (39,596)* lbm
Expansion Ratio	36.0
$\overline{\text{Ispv}}$	293.4 lbf-sec/lbm
$\overline{\text{Fv}}$	505,500 lbf
Total Impulse	93.55 X 10^6 lbf-sec
Burn Time	185 sec.
Max F/W	2.4

*Weight for FWC

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Figure 3.5.1-1. SRB-X One-Segment Design

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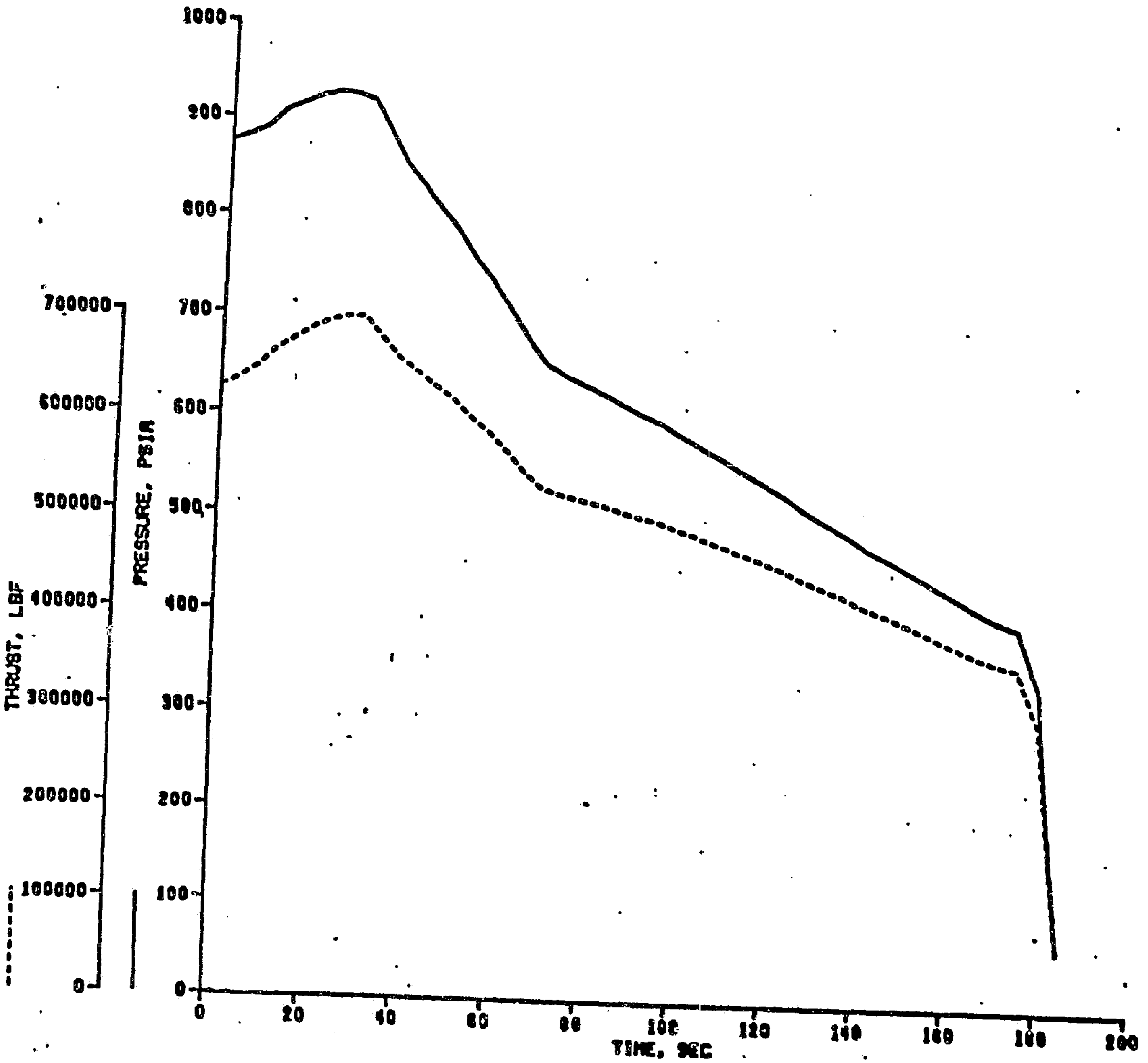

Figure 3.5.1-2. Configuration B One-Segment Pressure and Thrust Time Histories

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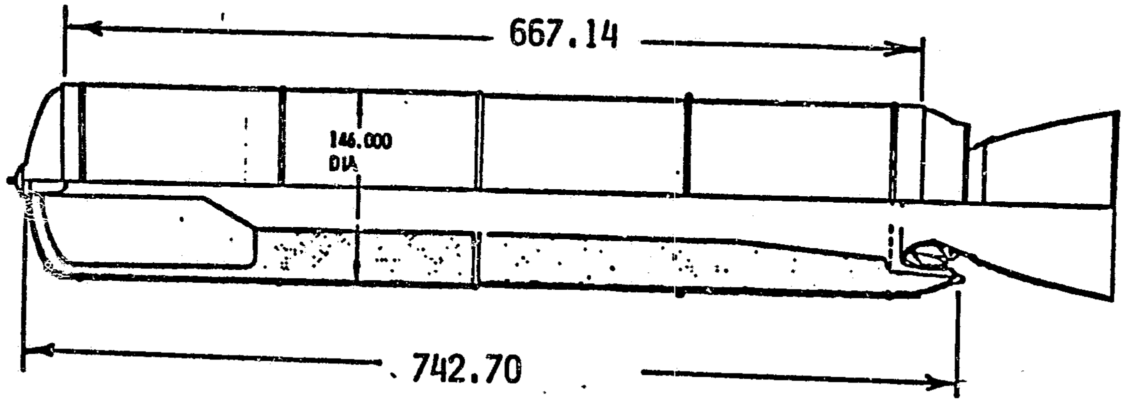
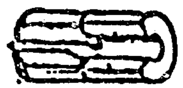
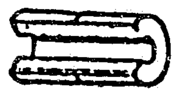


STS-SRM Common Components



Fwd Segment Case



Center Segment Case

Aft Dome

MOTOR SUMMARY

Propellant Weight	609,500
Inert Weight	77,605(60,729)* lbm
Expansion Ratio	18
$\overline{\text{Ispv}}$	285.1 lbf-sec/lbm
$\overline{\text{FV}}$	934,920 lbf
Total Impulse	173.28 X 10^6 lbf-sec
Burn Time	186 sec
Max F/W	2.9

*Weight for FWC

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Figure 3.5.1-3. Two-Segment SRM Initial Design

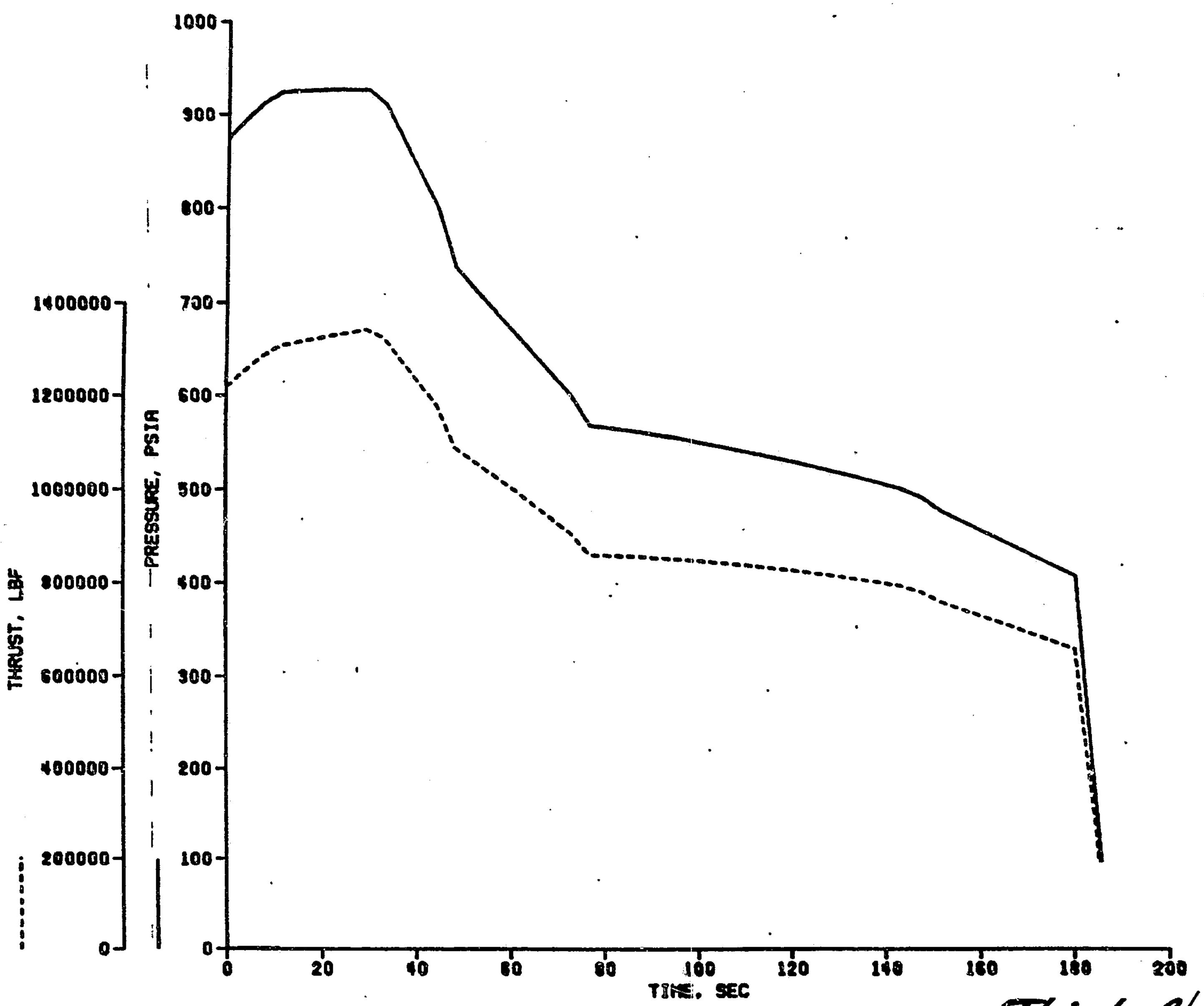

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Figure 3.5.1-4. Two-Segment Motor Pressure and Thrust Time Histories

relative to performance characteristics. A comparison of these options is shown in table 3.5.1-3. A burn time of 130 sec was selected because of low cost and acceptable performance. The 110-sec burn option had a higher thrust and, thus, less gravity loss but also had dynamic pressures of approximately 1000 psf and, consequently, was not selected. The key features of the selected three-segment SRM are shown in figure 3.5.1-5 with the thrust history shown in figure 3.5.1-6.

Four-Segment SRM—Stage 1. The four-segment SRM for stage 1 application was used in configurations A3, B2, B3, and B6. The SRM is by definition the same as that used for the shuttle. No additional performance or weight data are provided beyond those previously shown in table 3.5.1-1. The common elements between steel and filament wound cases are shown in figure 3.5.1-7.

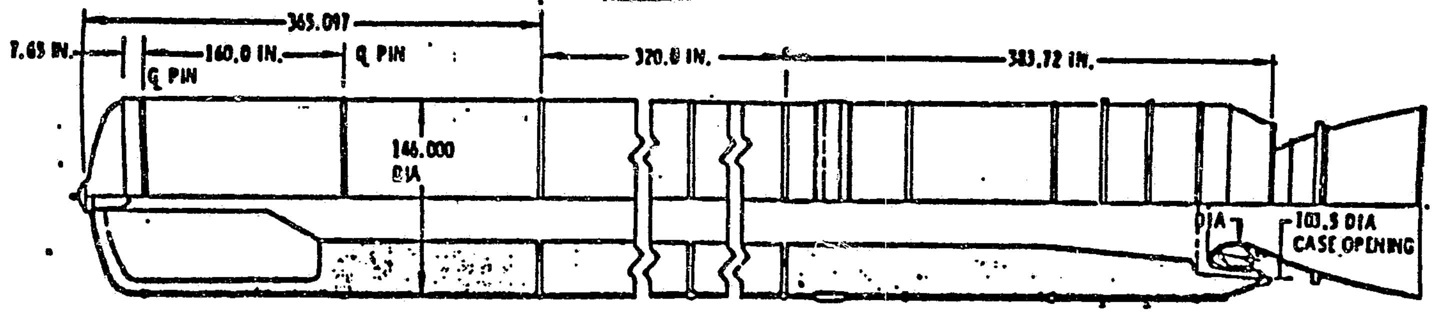
Four-Segment SRM—Stage 2. The four-segment SRM as a second stage had application only with the B2 vehicle concept. Three options were considered to provide a vehicle acceleration level of 3.5g or less. The comparison of the options is shown in table 3.5.1-4. Option A reduced burn rate and maintained the same nozzle as the high-performance motor (HPM); option B removed inhibitors from the end segments and reduced burn rate; and option C lowered the burn rate and reduced the nozzle throat. Option B was judged to offer the best overall characteristics. The characteristics of the selected motor are provided in table 3.5.1-5 and figure 3.5.1-8. Parametrics dealing with the sensitivity of Isp and nozzle length and weight versus expansion ratio are presented in figures 3.5.1-9, -10, and -11. Vehicle level performance trades have indicated that although higher Isp's are possible, the additional nozzle weight eliminates most of its benefit.

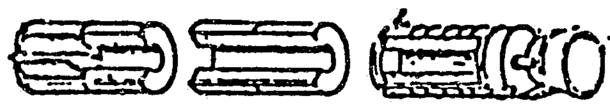
MX-Type First Stage (S1)—Stage 3. A derivative of the MX first stage was defined for application as an SRB-X third stage in the B6 configuration (4(2)-2-S1). The basic MX first-stage SRM is shown in figure 3.5.1-12. The SRM uses a filament wound case and TP-H1202 propellant. Thrust and pressure time histories are shown in figure 3.5.1-13. The greatest challenge in the use of this SRM was tailoring the thrust profile to provide a vehicle acceleration level no greater than 3.5g's. Several nozzle expansion ratios were investigated and are compared in table 3.5.1-6. Because this option was being considered as an alternative to the Titan second (T2) stage, it was decided the lengths of these two candidates should be the same. Accordingly, an expansion ratio of 50 was found to provide a length comparable to the stretch version of the Titan second stage, which is described in the next paragraph.

Table 3.5.1-3. SRB-X Three-Segment SRM Comparisons

Parameter	As Is	Rbo Increase to Match MEOP	R_{TI} Decrease	Rbo to Match 130 sec
Inert Weight	Reference	Same	Increased	Same
Burn Time	143	110	132	130
Burn Rate @1000 psia	0.423	0.506	0.423	0.451
Max F/W	2.1	2.75	2.3	2.3
Ispv	267.2	267.8	271.8	267.4
Cost Impact	Minimal	Low	Medium	Low

REMOVE CENTER SEGMENT & INCREASE R_{b0} TO MATCH 130 SEC





Burn Rate	0.451 ips @1000 psi	Uses STS-SRM Common Components Throughout with One Center Segment Removed
Burn Time (sec)	130 sec	
MEOP	845 psia	
EXPANSION RATIO	7.72	
Ave Vac Thrust	1,720,472 lbf	
Delivered Isp Vac	267.4 lbf-sec/lbm	
Ave Chamber Pressure	438 psia	
Total Impulse Delivered	223,662,279 lbf-sec	
Propellant	835,495 lbm	
Thrust/Weight	2.3	
Inert Weight	120,435 (92,134)* lbm	

*Weight for FWC

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Figure 3.5.1-5. SRB-X Three-Segment SRM Recommended Configuration

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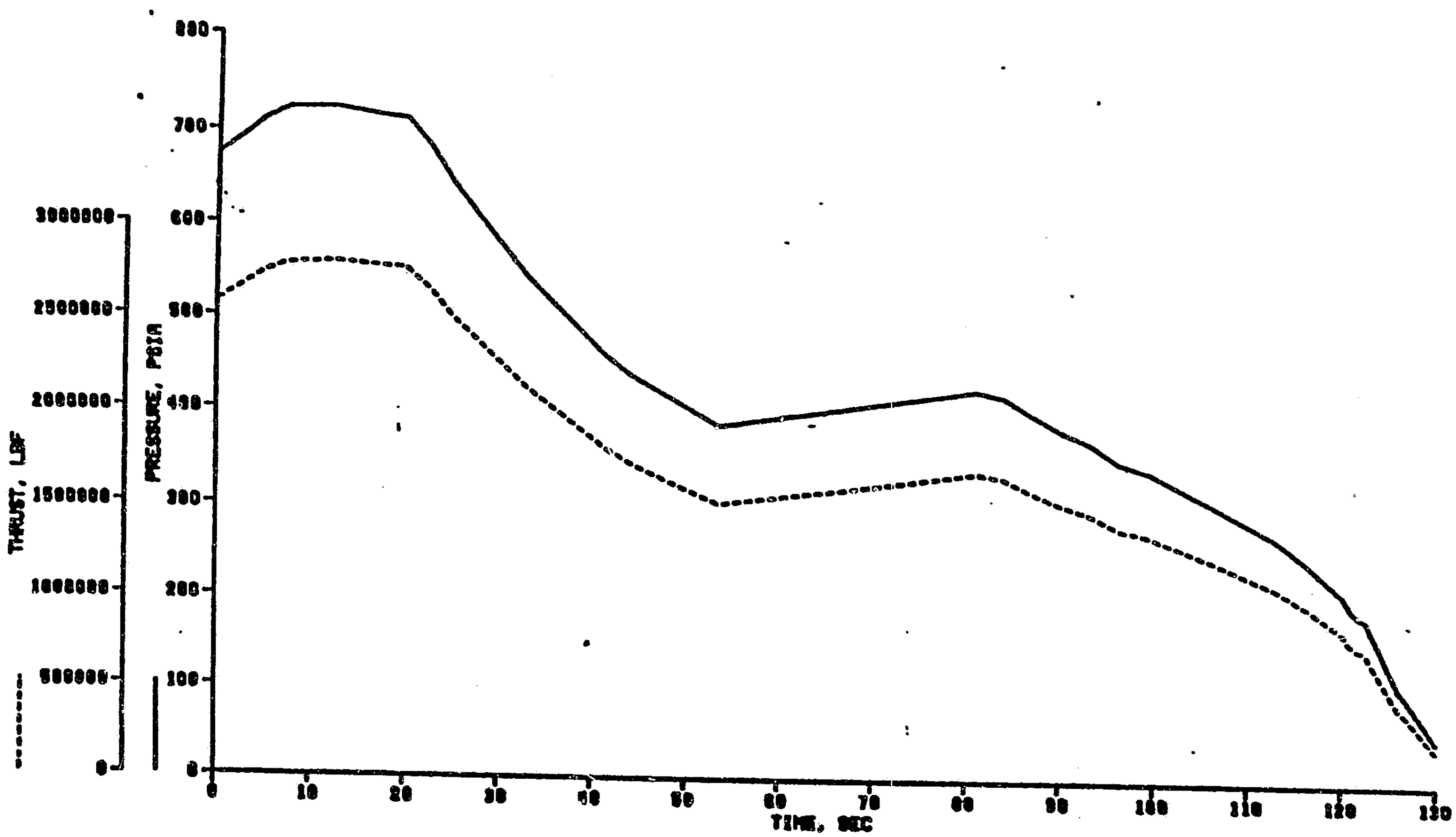

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Figure 3.5.1-6. SRB-X Three-Segment SRM Pressure and Thrust Time Histories

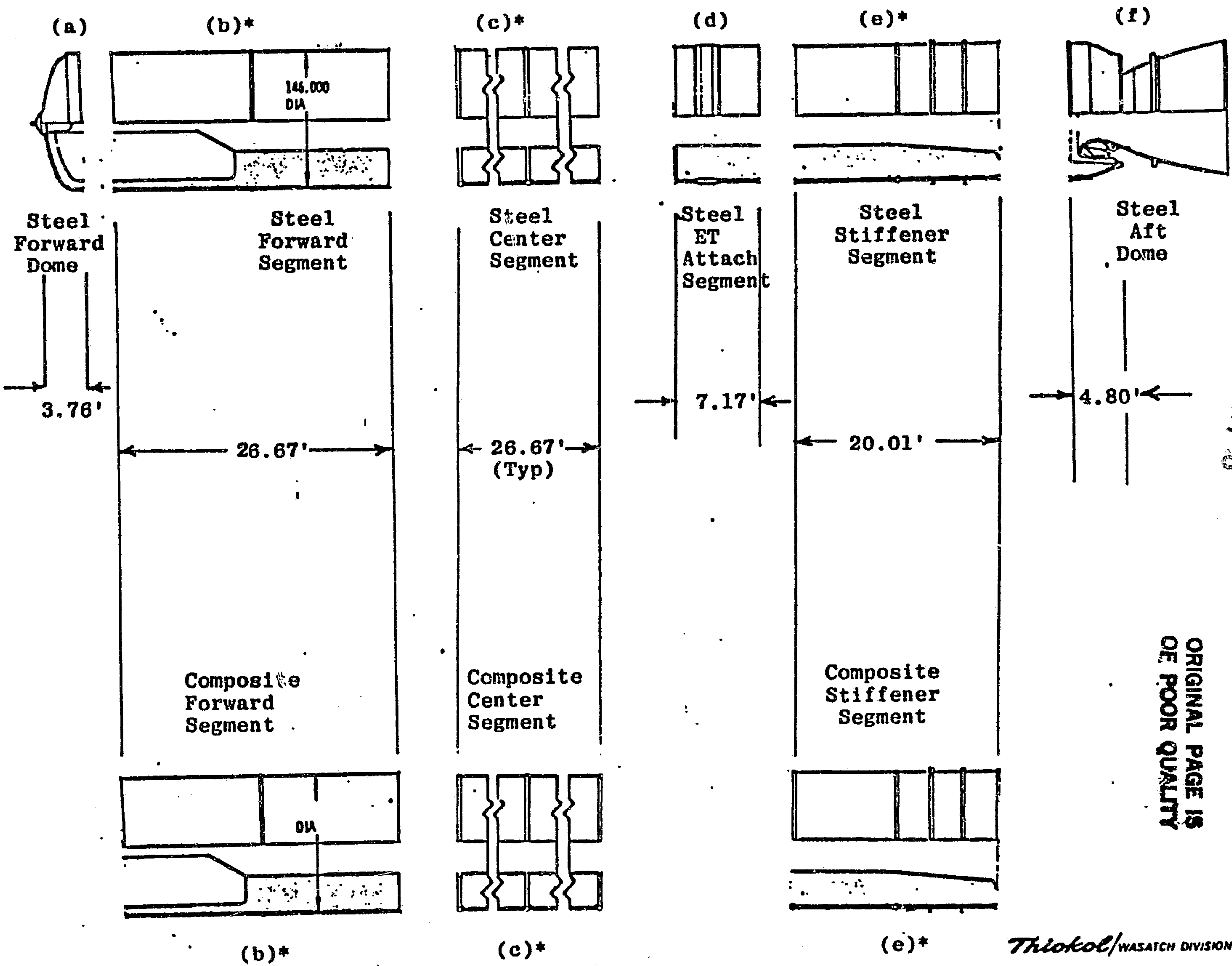

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Figure 3.5.1-7. Four-Segment First-Stage SRM

Table 3.5.1-4. SRB-X Four-Segment Second-Stage SRM Option Comparisons

Parameter	Standard HPM	Reduced R_{bo}	Inhibitor and R_{bo}	R_{bO} & R_{TI}
Inert Weight	Reference	Same	Same	Increase
Burn Time (sec)	125	200	155	191
Burn Rate a1000	.423	.310	.370	.280
Max F/W	5.4	3.3	3.5	3.6
$\overline{Ispv}$	267.8	266.8	267.5	276.5
Cost Impact	None	Low	Low	Medium

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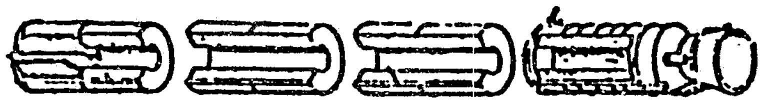
Table 3.5.1-5. SRB-X Four-Segment Second-Stage SRM Performance Summary

Burn Rate	0.37
Burn Time (sec)	155
MEOP	878
Exit Plane Diameter	--
Ave Vac Thrust	1,914,932
Delivered Isp Vac	267.5
Ave Chamber Pressure	483
Total Impulse Delivered	296,232,210
Propellant	1,107,450
Thrust Weight	3.5
Inert Weight	

Uses STS Common Components Throughout



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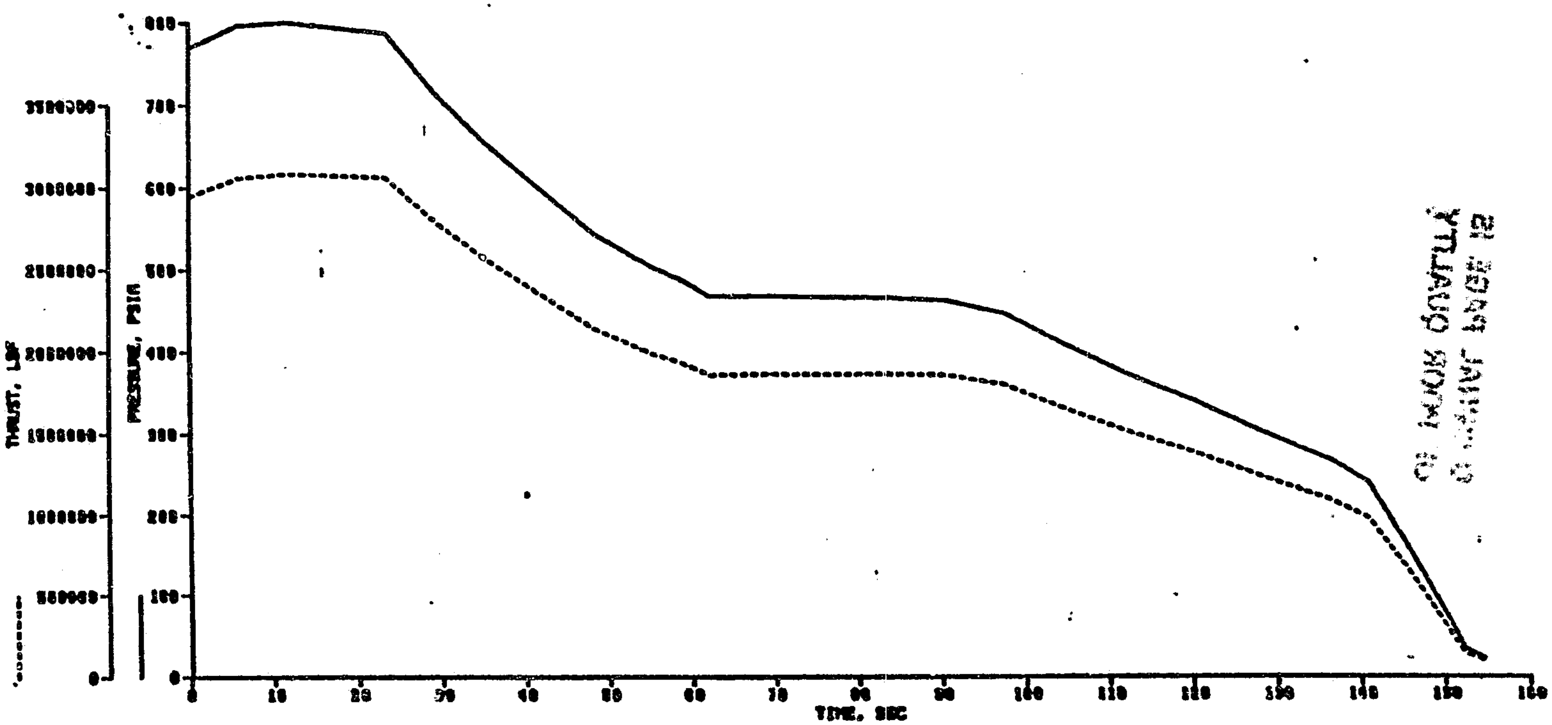

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Figure 3.5.1-8. SRB-X Four-Segment Second-Stage SRM Pressure and Thrust Time Histories

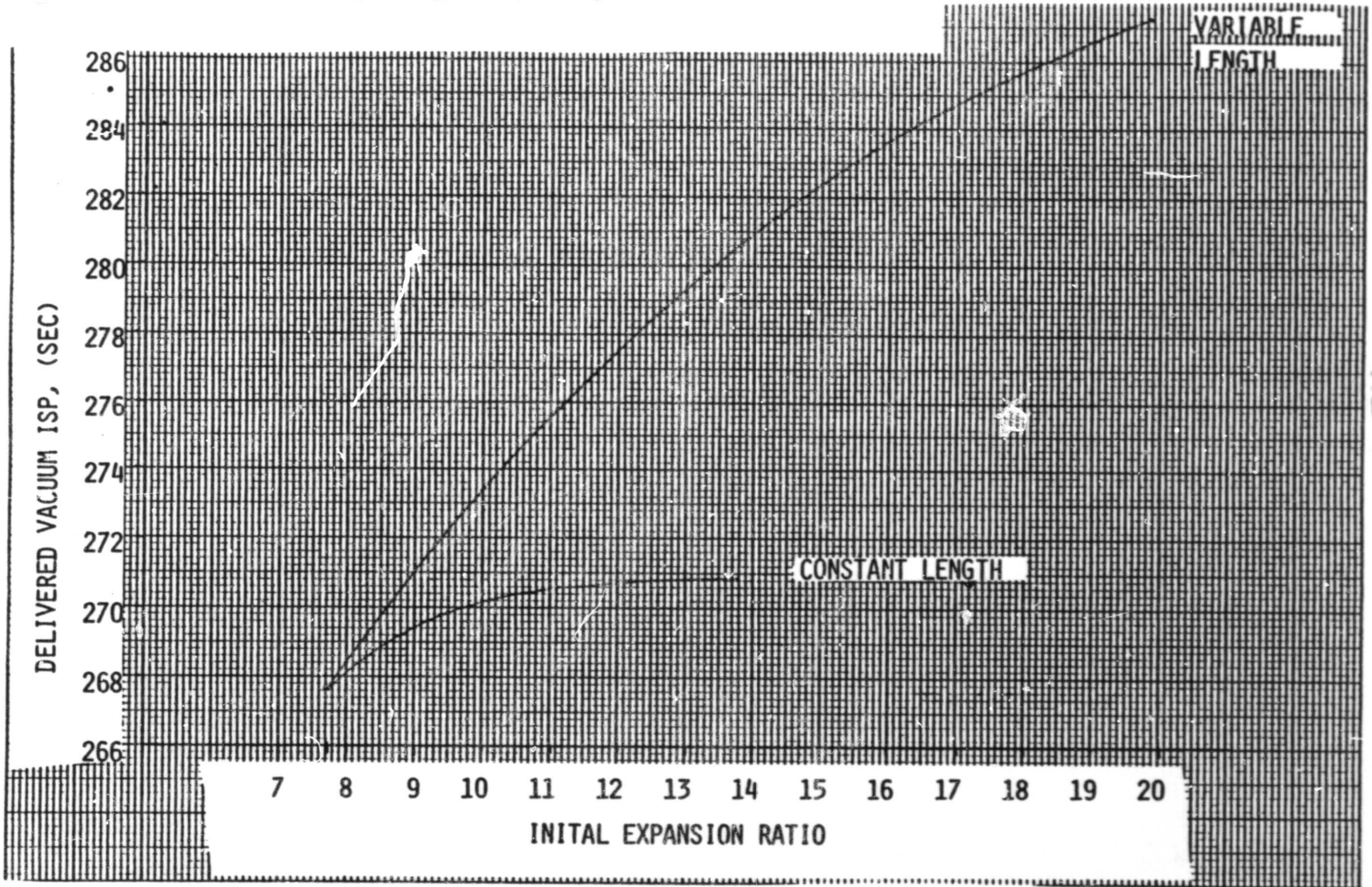

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Figure 3.5.1-9. Isp Versus Expansion Ratio—Four-Segment Second Stage

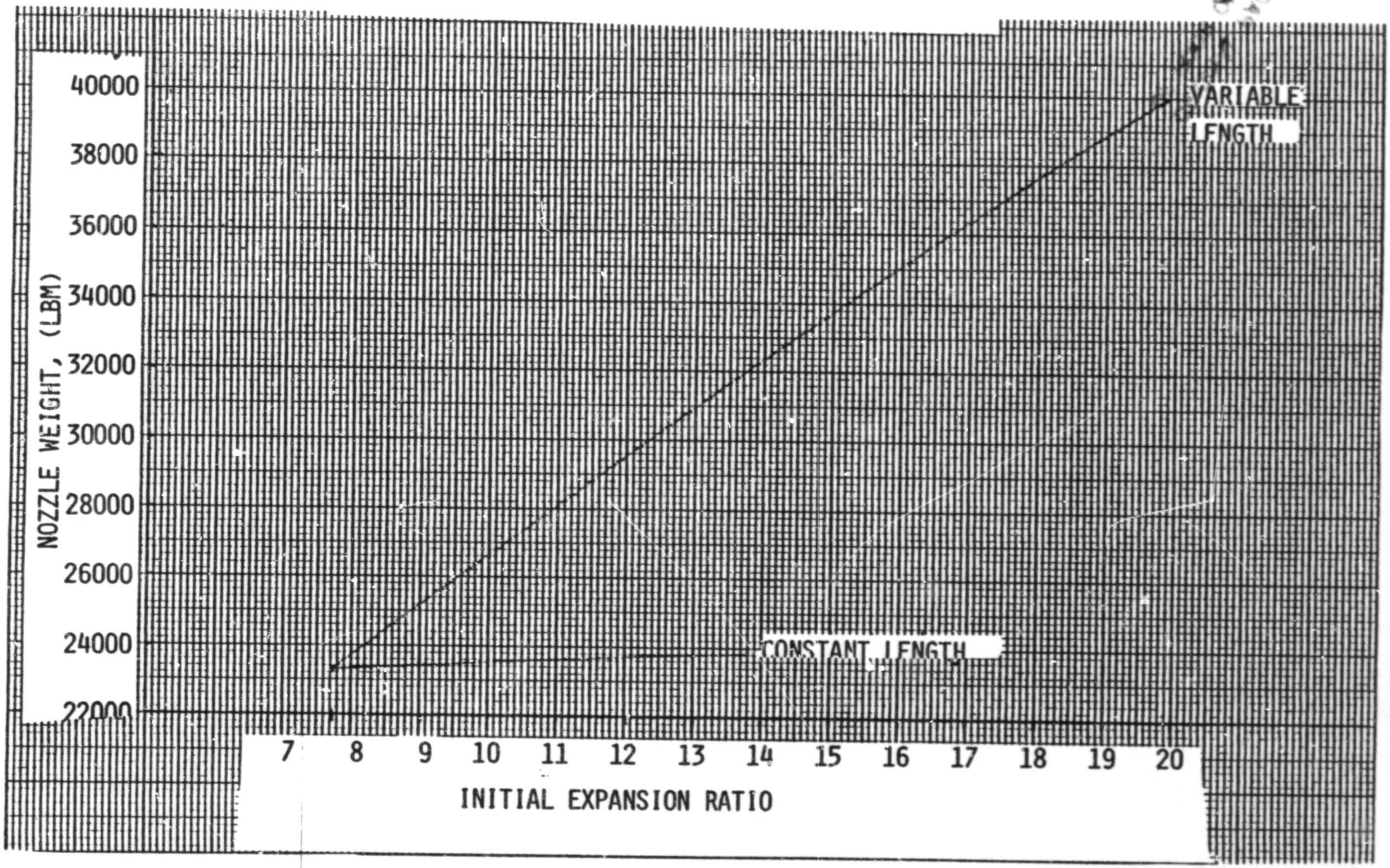

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Figure 3.5.1-10. Nozzle Weight Versus Expansion Ratio—Four-Segment Second Stage

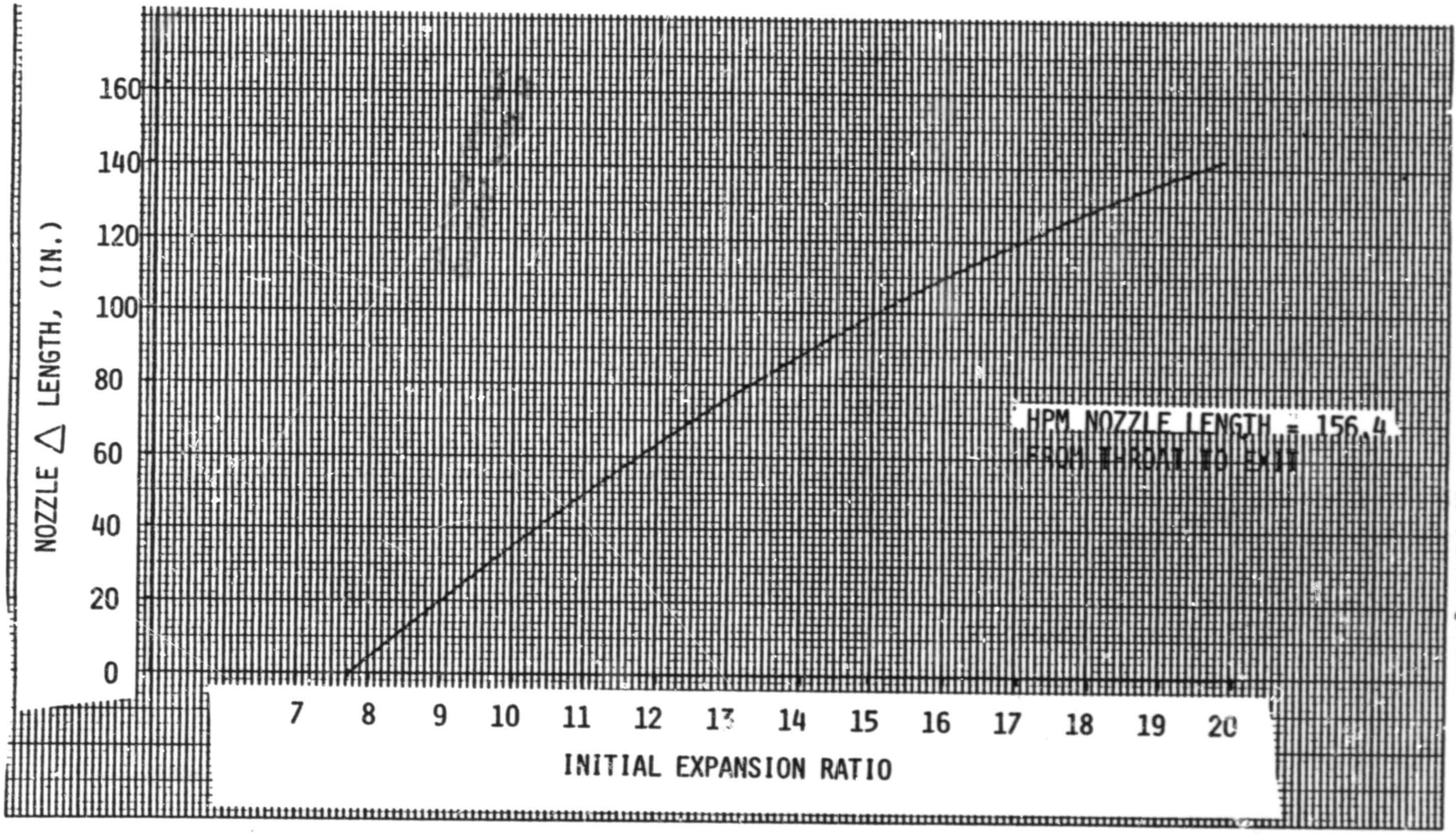

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Figure 3.5.1-11. Nozzle Length Versus Expansion Ratio—Four-Segment Second Stage

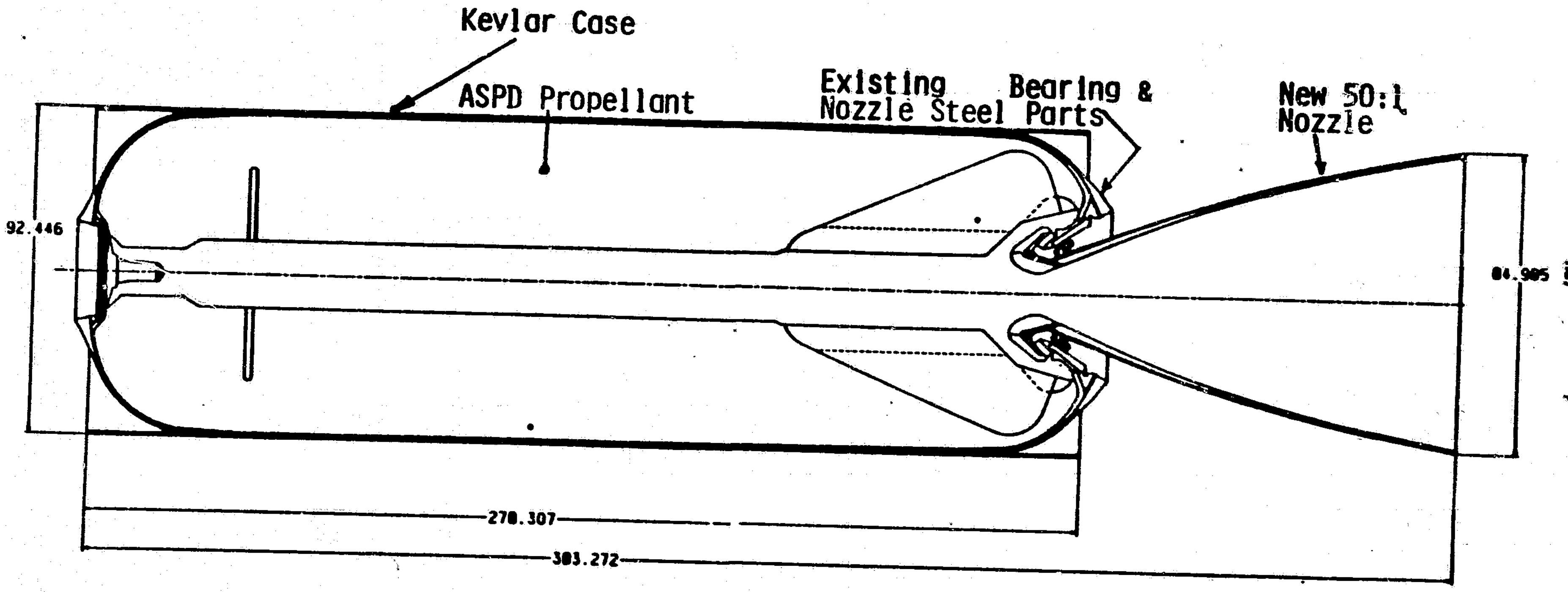

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Figure 3.5.1-12. S-1 Third-Stage SRM

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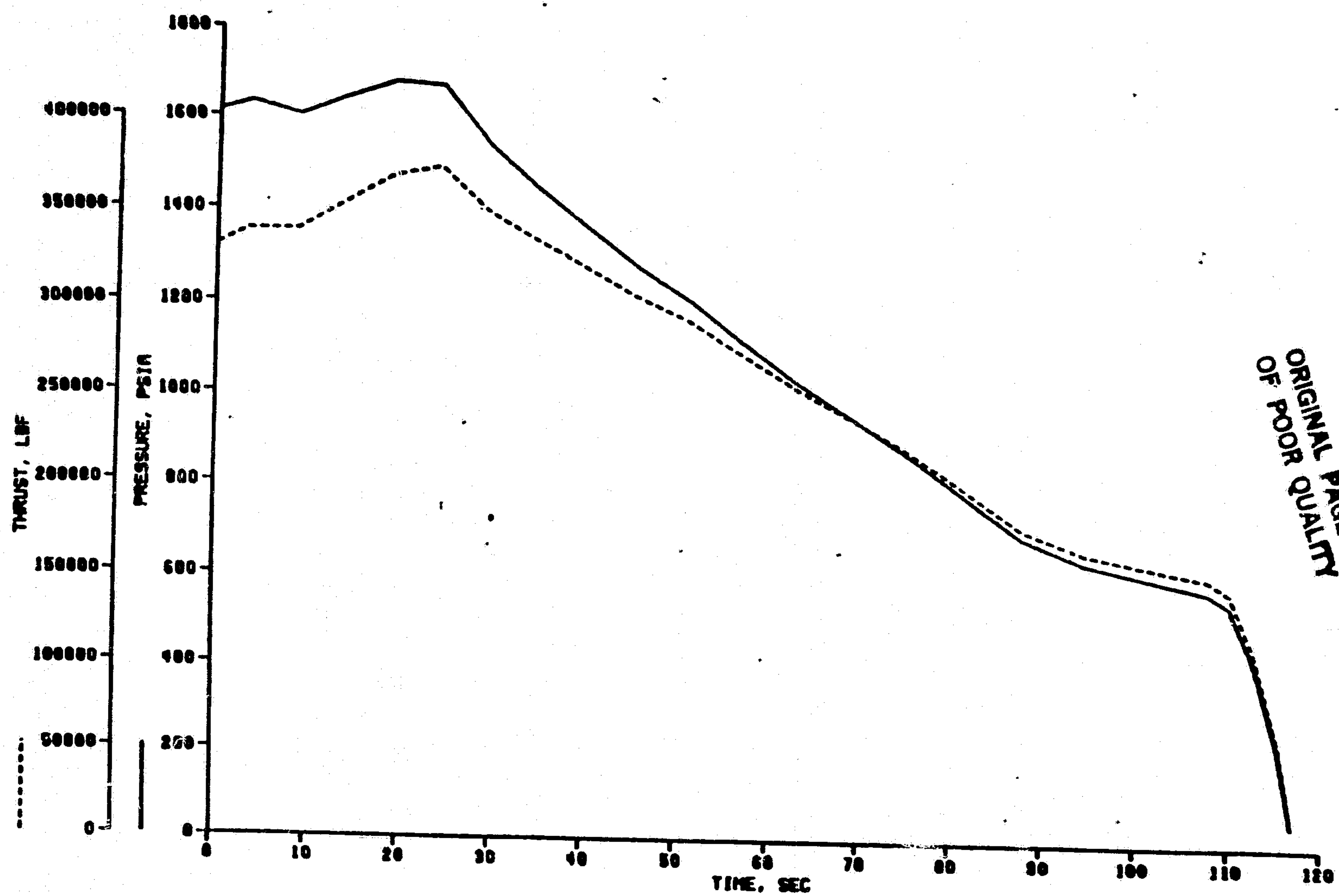

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Figure 3.5.1-13. S-1 Third-Stage SRM Pressure and Thrust Time Histories

Table 3.5.1-6. SRB-X Upper Stage (S-1) Motor Performance Summary

	NOZZLE EXPANSION RATIO		
	E = 30	E = 50	E = 100
BURN RATE (IN/SEC)	0.30	0.30	0.30
BURN TIME (SEC)	111.60	111.60	111.60
MEOP (PSIA)	1,856.00	1,856.00	1,856.00
EXIT PLANE DIAMETER (IN)	65,000.00	83.90	118.70
AVE VAC THRUST (LBF)	255,607.00	262,359.00	269,977.00
DELIVERED ISP VAC (SEC)	296.40	304.20	313.00
AVE CHAMBER PRESSURE (PSIA)	1,098.00	1,098.00	1,098.00
TOTAL IMPULSE DELIVERED (LBF-SEC)	28,512,960.00	29,266,115.00	30,115,934.00
PROPELLANT EXPELLED (LBM)	96,203.00	96,203.00	96,203.00
THRUST WEIGHT	3.10	3.20	3.30
INERT WEIGHT	11,070.00	11,355.00	11,870.00

3.5.1.2 Liquid Stages

The first screening analysis of some of the final six configurations (A3 and B4) indicated a LEO and polar performance deficiency when using only three stages. During the second screening analysis, a storable fourth stage was added to these configurations in the form of a cluster of four Delta core stage 2's. A more effective means of providing approximately the same total impulse was employed for the third screening by using a stretch version of the Titan core stage II (called T2S), involving an increase of 41,000 lb in propellant loading. Primary benefits were shorter length, less inert weight, and less integration complexity. Characteristics follow.

Characteristic	(4) Delta stage 2	T2S
W_p (1000 lb)	51,500	107,400
I_{sp} (sec)	319	318
Inerts (1000 lb)	7000	8300
Delta L (ft)—beyond basic T2	+20	+7
Diameter (ft)	15	10
Issues	Integration complexity Control/avionics	Minimum

3.5.2 Structural Analysis

A preliminary loads and structures assessment was performed on typical class A and B vehicles considered during the third screening. The investigated vehicles are those designated as A3, B3, and B4. Key characteristics for the vehicles are shown in figure 3.5.2-1. These vehicles were analyzed for axial load and bending moment effects on stage 1 and 2 SRM's and on upper stage structures. In addition, preliminary weight differences concerning the payload shroud for these configurations were identified.

3.5.2.1 Design Load

Axial load factors for the three typical vehicles are presented in table 3.5.2-1. Operation of stages 1, 3, and 4 shows relatively low factors. The axial load factor shown for stage 2 operation reflects the use of a square thrust trace, which was all that was available at the time. Use of a square thrust trace resulted in an axial load factor in excess of 6g's and indicated a requirement for a substantially regressed thrust trace. Since thrust regression yields decreased performance, the degree of thrust regression was subsequently targeted to be no larger than that necessary to ensure that payloads would experience acceleration levels equivalent to those provided by the shuttle. The

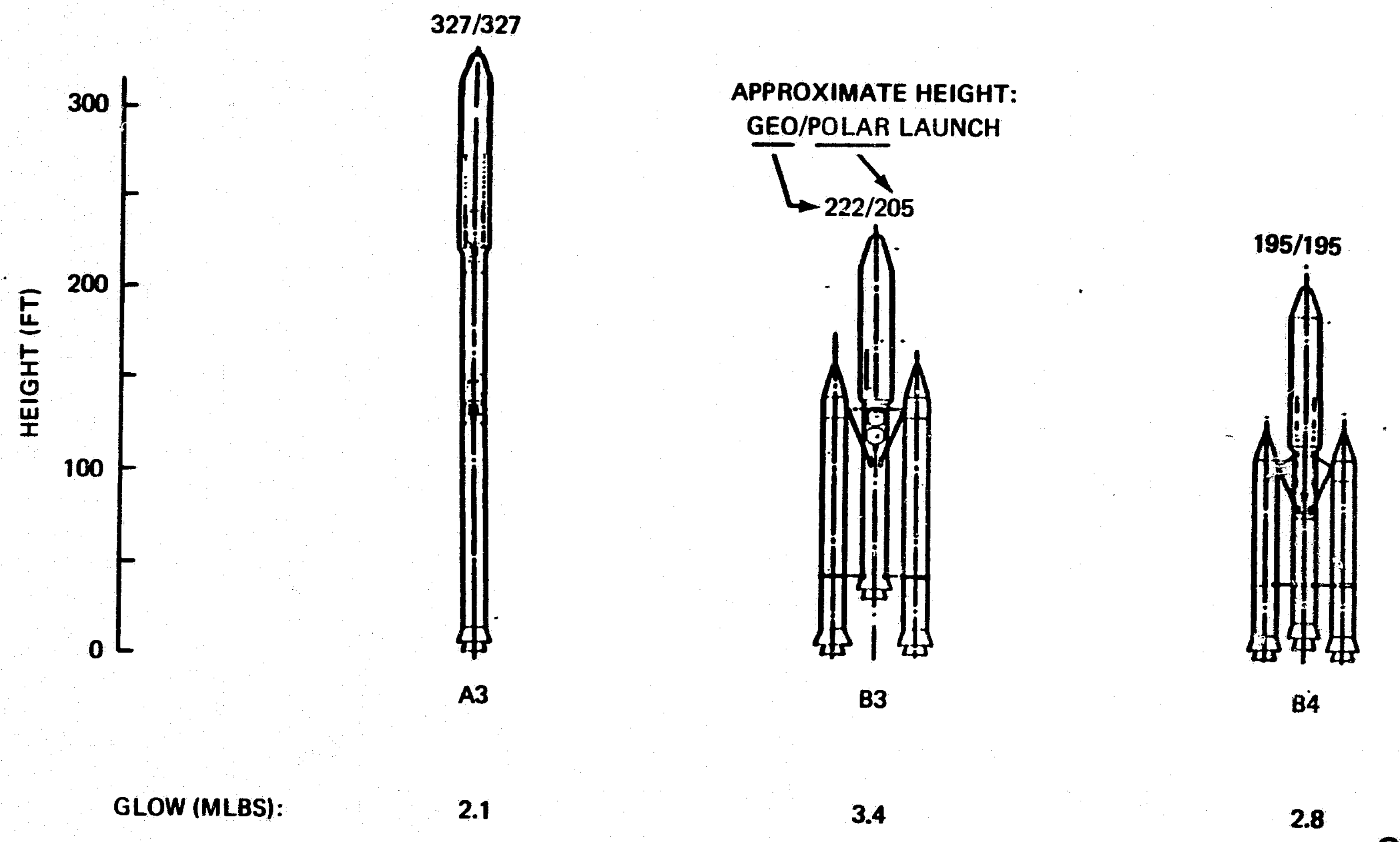


Figure 3.5.2-1. Vehicles for Structural Analysis

Table 3.5.2-1. *Axial Load Factors*

GEO MISSION

	STS	A3	B3	B4	
LIFTOFF					
TRANSIENT		TBD	TBD	TBD	
STEADY STATE ONSET	1.40	1.26	1.55	1.64	
MAX q		1.80	1.70	1.50	
STAGE 1 PRE-BURNOUT MAX		1.80	2.80	2.10	
STAGE 2 BURNOUT					
SQUARE THRUST TRACE		6.40	6.10	6.10	ISSUE: STS P/L COMPATIBILITY
REGRESSED THRUST TRACE		TBD	TBD	TBD	
STAGE 3 (T2) BURNOUT *		2.00	2.00	2.00	
STAGE 4 (D-IT) BURNOUT *		2.50	2.50	2.50	

* REF GEO P/L WEIGHT = 8,000 LB

SRB-X load factors that would yield the same acceleration levels are indicated in table 3.5.2-2. Shuttle payloads are designed for an axial load factor of 4.5g ultimate (3.2g limit times 1.4 UFS) for both liftoff transient and boost conditions. This ultimate load factor limitation applies to SRB-X. However, because SRB-X is an unmanned system for which UFS = 1.25 applies, it is possible to allow SRB-X to be subjected to an axial load factor greater than the shuttle's 3.2g limit. If the SRB-X axial load factor is restrained to 3.6g limit (3.2g x $\frac{1.40 \text{ UFS}}{1.25 \text{ UFS}}$), 100% shuttle payload compatibility is ensured. A factor of 4.5g is possible but is peculiar to payload design.

The key trajectory parameters leading to the structural design max q-alpha value are shown in table 3.5.2-3. Liftoff steady state thrust-to-weight (T/W) ratios for vehicles A3, B3, and B4 are 1.26, 1.55, and 1.64, respectively. These variations in liftoff T/W result in considerable variations in both maximum dynamic pressure (max q) and in the flight parameters and conditions at which max q occurs. Structural design max q-alpha values were obtained by assuming that the vehicle angle of attack (alpha) at max q can be approximated by applying a 180-ft/sec velocity vector at a right angle to the vehicle relative velocity. The resulting structural design max q-alpha values (lb/ft^2-deg) for vehicles A3, B3, and B4 are 3640, 6020, and 6700, respectively.

The distribution of bending moment resulting from the max q-alpha condition is indicated in figure 3.5.2-2 for vehicles A3, B3, and B4. Maximum bending moment values and locations are as follows:

a. A3 vehicle: 43 x 10^6 in-lb at aft end of stage 2 SRM (SRM unpressurized).
b. B3 vehicle: 47 x 10^6 in-lb near center of stage 3 (T2 stage).
c. B4 vehicle: 56 x 10^6 in-lb near center of stage 3 (T2 stage).

3.5.2.2 SRM Structural Assessment

The structural capability of an SRM is generally expressed in terms of pure axial load and pure bending moment, where tension/tension side capability is governed by segment joint strength and compression/compression side capability is governed by case buckling. The capability of a shuttle SRM lightweight steel case to carry ultimate externally applied loads (pure axial load, pure bending moment) is indicated in table 3.5.2-4 for the unpressurized condition and for a typical pressurized condition of 660 psi for vehicles A3, B3, and B4. A comparison of maximum applied loads to applied load capability of the SRM's is in figure 3.5.2-3. As indicated, the applied loads capability of a shuttle SRM lightweight steel case is several orders of magnitude greater than the worst case externally applied loads.

Table 3.5.2-2. Maximum Axial Load Factors and Shuttle Payload Compatibility

SHUTTLE PAYLOADS

- ULTIMATE FACTOR OF SAFETY = 1.40
- LAUNCH LOAD FACTORS (JSC 0770, VOL X(V))

$$\left.\begin{array}{l} \bullet\ \text{LIFTOFF:} \\ \quad NX = -0.2/-3.2 \\ \quad NY = \pm 1.4 \\ \quad NZ = \pm 2.5 \\ \text{BOOST:} \\ \quad NX = -3.17 \\ \quad NY = 0 \\ \quad NZ = -0.6 \end{array}\right\} \text{LIMIT LOAD FACTORS TO BE CONSIDERED IN ALL COMBINATIONS}$$

SRB-X PAYLOADS

- ULTIMATE FACTOR OF SAFETY = 1.25
- AXIAL LOAD FACTOR LIMITATION:

$$NX = NX_{SHUTTLE} \times k_{UFS} \times k_{LATERAL\ LOADS}$$

$$= -3.2 \times \frac{1.40}{1.25} \times (1 \rightarrow 1.25)$$

$$= \begin{cases} -3.6\ ; & \text{100\% STS PAYLOAD COMPATIBILITY} \\ -4.5\ ; & \text{STS PAYLOAD COMPATIBILITY IS DEPENDENT ON PERCULUARITIES OF PAYLOAD STRUCTURAL SYSTEM. REQUIRES THAT STRUCTURAL MEMBERS WHICH CARRY AXIAL LOAD ALSO BE PRIME MEMBERS IN CARRYING LATERAL LOADS. (i.e. CANTILEVERED PAYLOADS)} \end{cases}$$

Table 3.5.2-3. Structural Design Maximum Q-Alpha Conditions

	A3	B3	B4	
TIME (SEC)	80	50	40	TRAJECTORY DATA (AT MAX Q)
ALTITUDE (FT)	44,000	31,000	22,000	
MACH NUMBER	1.5	1.4	1.1	
RELATIVE VELOCITY (FPS)	1,483	1,362	1,093	
STAGE THRUST (10^6 LBF)	2.5	4.5	3.5	
AXIAL LOAD FACTOR (G)	1.8	1.7	1.5	
MAX q (PSF)	527	803	713	
α (DEG) [1]	6.9	7.5	9.4	SELECTED FOR FIRST QUARTER PRELIMINARY STRUCTURAL ASSESSMENT
MAX $q\alpha$ (PSF-DEG)	3,640	6,020	6,700	
STAGE 1 THRUST VECTOR ANGLE (DEG)	0.9	1.3	2.6	OUTPUT DATA (BASED ON MOMENT BALANCE)
LATERAL LOAD FACTOR (G)	0.06	0.12	0.20	
MAX BENDING MOMENT (10^6 IN-LB)				
CORE	43	47	56	
STRAP-ON	——	18	27	

[1] $\alpha^{\circ} = \text{ARC TAN} \dfrac{180}{\text{REL VEL}}$

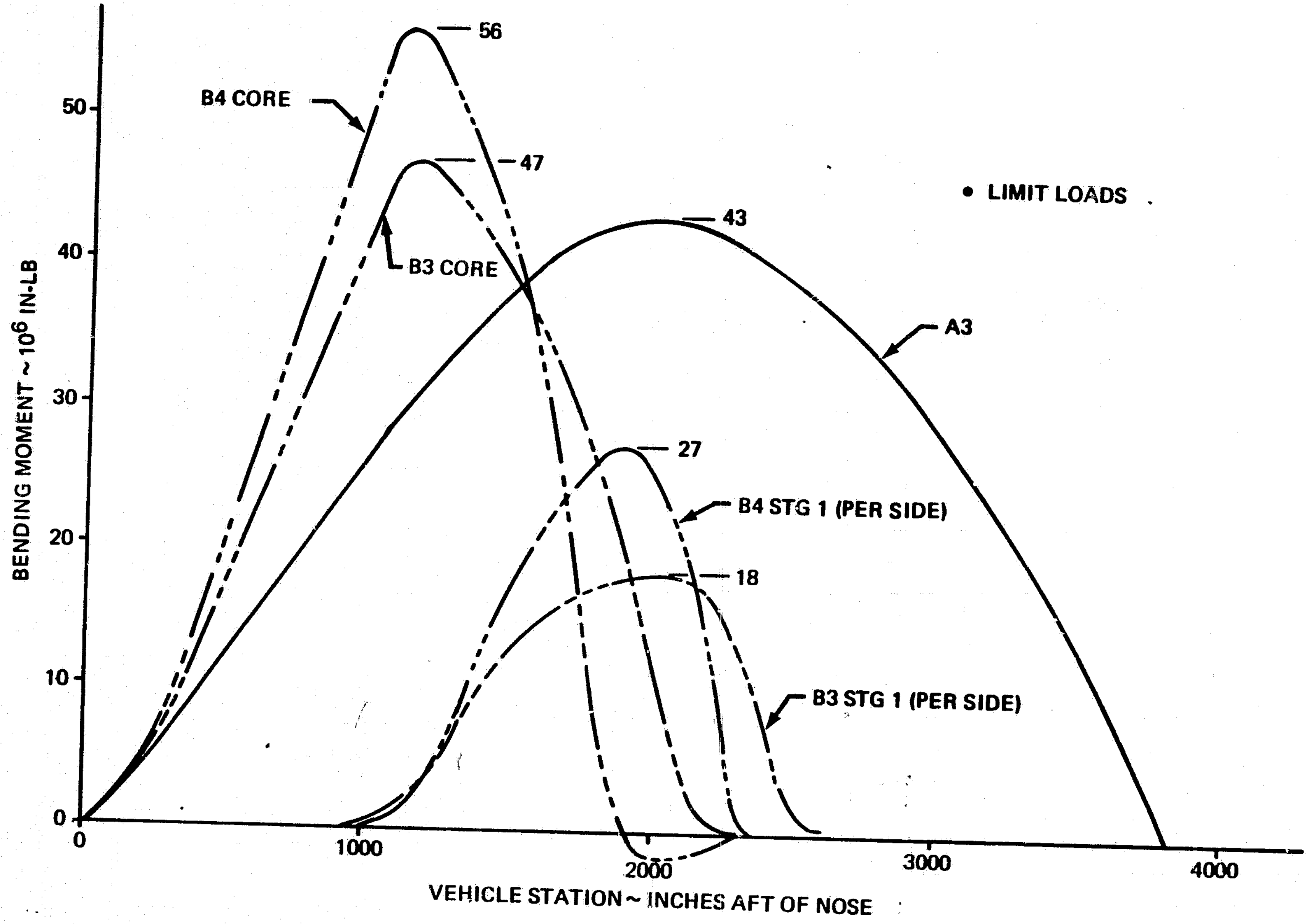


Figure 3.5.2-2. Bending Moment at Structural Design Maximum Q-Alpha

Table 3.5.2-4. SRM Structural Capability—Ultimate Externally Applied Loads

- LIGHTWEIGHT STEEL CASES
- MEOP = 1016 PSIA
- UFS = 1.40 (STS), 1.25 (SRB-X)

	UNPRESSURIZED	PRESSURIZED (660 psi 1)
PURE AXIAL LOAD (LB):		
TENSION	25.7×10^6	11.9×10^6
COMPRESSION	13.4×10^6	24.5×10^6
PURE BENDING MOMENT (IN-LB):		
TENSION SIDE	937×10^6	433×10^6 2
COMPRESSION SIDE	577×10^6 2	980×10^6

1 TYPICAL INTERNAL PRESSURE AT STRUCTURAL DESIGN MAX $q\alpha$ CONDITION (A3,B3,B4)

2 CRITICAL SIDE

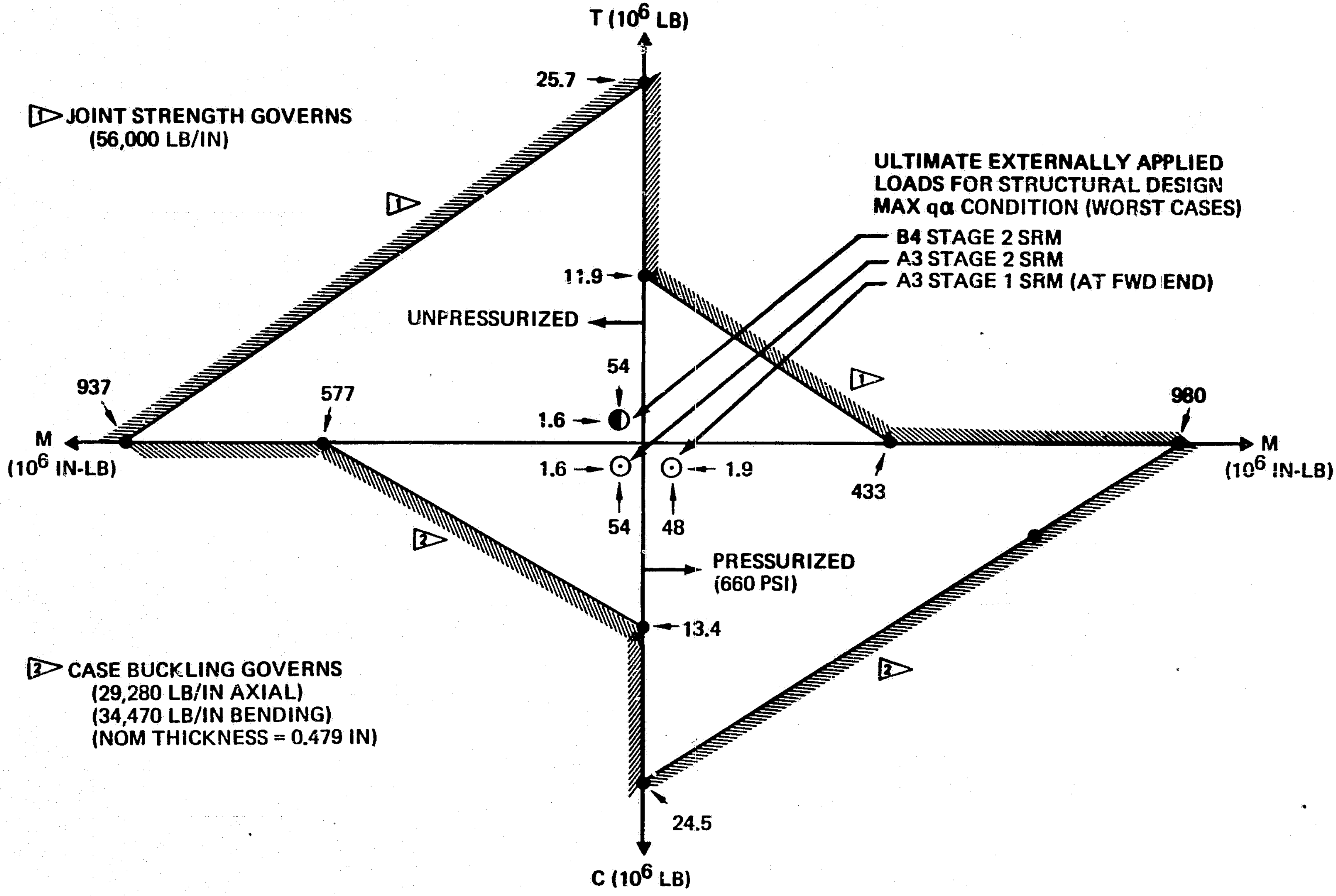


Figure 3.5.2-3. SRM Structural Compatibility

3.5.2.3 Structural Integration—Payload/Upper Stages/Shroud

The second structural area of investigation was that of establishing a concept for sustaining bending moment, axial load, and lateral load in the upper portion of the vehicle—specifically the structural interfaces involving the payload, upper stages, and shroud. The analyses were performed for a GEO mission with the indicated payload characteristics and a center of gravity (CG) 40% above the truss adapter. The selected concept is shown in figure 3.5.2-4 and includes a 16.7-ft-diameter shroud, approximately 122 ft in length. Utilization of existing upper stages requires that the aerodynamic bending moment be load shared between the upper stages and shroud by means of a standard forward bearing reaction (FBR) system. The FBR also minimizes the diameter of the shroud for a given payload diameter as it reduces the amount of relative motion between shroud and payload. Shrouding of the Centaur was the result of thermal considerations. The Titan core stage II is included within the shroud because it did not have sufficient strength to sustain the maximum bending moment. Data supporting the selected concept are presented in subsequent paragraphs.

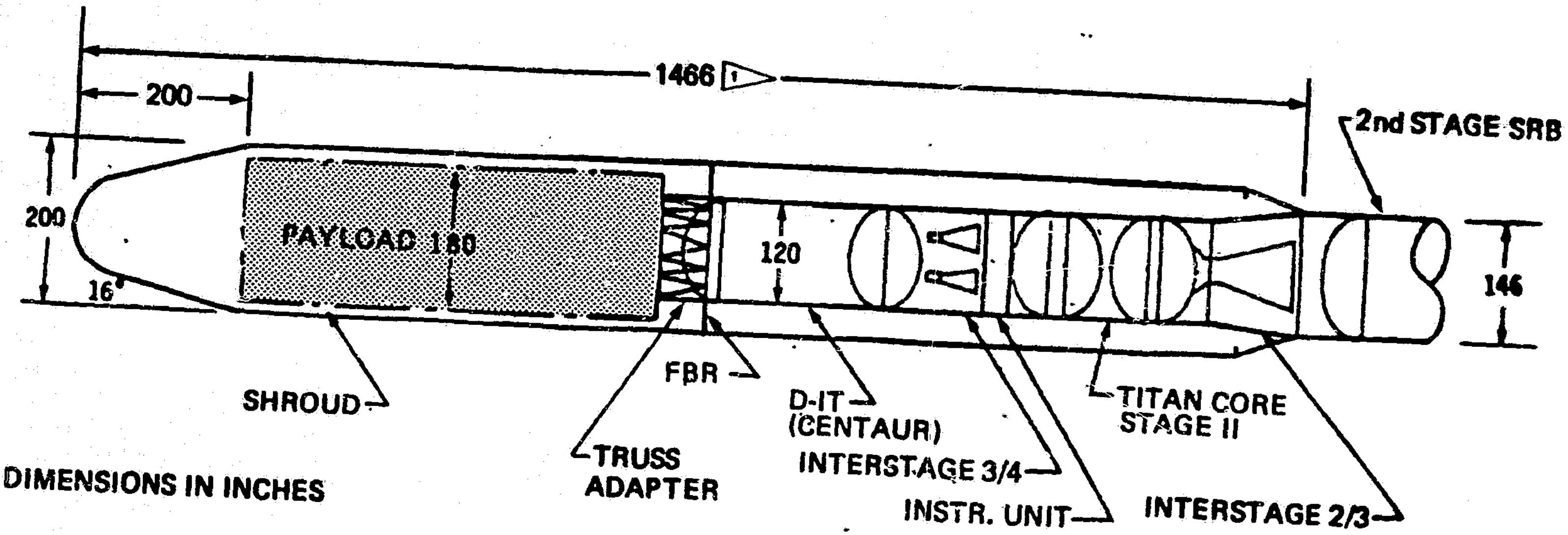
Centaur D-IT Assessment. Principal areas concerning the use of the Centaur D-IT involved the applicability of its FBR system, truss adapter, and strength of the fuel tank to sustain the expected loads.

The key features of the FBR, as used with Centaur within a 14-ft-diameter Centaur standard shroud, are shown in figure 3.5.2-5. The FBR consists of a lateral system of struts (plus installation and separation provisions) which attaches to the Centaur stage stub adapter forward ring. The FBR provides interactive load support during launch transient conditions and prevents excessive relative deflection of shroud to payload during maximum aerodynamic loading. Additionally, its use allows shroud diameter to be minimized. The existing system is designed to an omnidirectional shear plane limit load of 20,000 lb and 20,000 lb/in spring constant. In the event that excessive shroud aerodynamic load is to be imposed on Centaur, the stiffness of the system can be lowered to avoid Centaur redesign. SRB-X utilization of the existing Centaur FBR struts is an assessment issue.

The constraints of the existing D-IT truss adapter relative to the anticipated GEO payloads for SRB-X are shown in figure 3.5.2-6. The GEO payload weight range of interest varies from a minimum of 8000 lb (first quarter design goal) to a maximum of 12,000 lb (A4 configuration). . The existing D-IT truss adapter was designed to accommodate an 8000-lb payload having its CG located 190 in about the truss adapter. If this is reduced to 125 in, payload weight capability increases to 12,000 lb. Relative to

PAYLOAD ASSUMPTIONS

- WEIGHT= 8000 LBS
- LENGTH= 42 FT



DIMENSIONS IN INCHES

ASSESSMENT

- CENTAUR FORWARD BEARING REACTION (FBR) IS ADEQUATE IN STRENGTH AND MINIMIZES PAYLOAD SHROUD DIAMETER
- D-IT TRUSS ADAPTER IS ADEQUATE FOR PAYLOAD CONDITIONS
- D-IT FUEL TANK STRENGTH IS ADEQUATE WITH CURRENT LOCKUP PRESSURE CAPABILITY OF 23.1 PSIA AND USE OF THE FBR
- TITAN CORE STAGE II MUST BE SHROUDED TO SUSTAIN MAXIMUM BENDING LOADS. SHROUDING ALSO SIMPLIFIES STAGE 1/2 CLUSTER STRUCTURE.

Figure 3.5.2-4. Structural Integration—Payload/Upper Stages/Shroud

- LATERAL SYSTEM OF STRUTS INTERCONNECTING SHROUD AND CENTAUR STAGE STUB ADAPTER FORWARD RING
- PROVIDES INTERACTIVE LOAD SUPPORT DURING LAUNCH TRANSIENT CONDITION AND PREVENTS EXCESSIVE RELATIVE DEFLECTION OF SHROUD TO PAYLOAD DURING MAXIMUM AERODYNAMIC LOADING
- CHARACTERISTICS OF SYSTEM INSTALLED ON CENTAUR STANDARD SHROUD:
  - LIMIT DESIGN LATERAL FORCE = 20,000 LBF (OMNI-DIRECTIONAL)
  - SPRING CONSTANT = 20,000 LBF/IN.

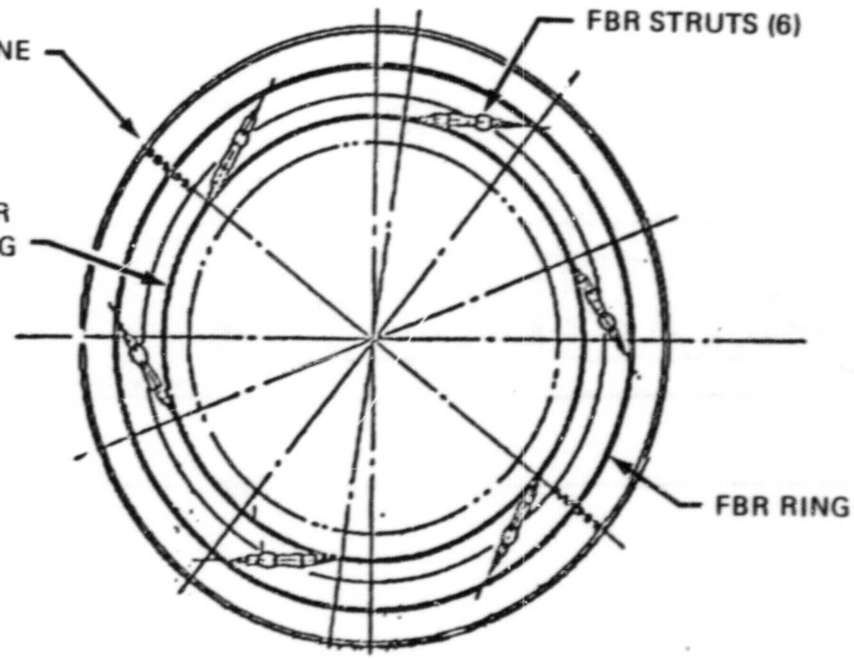


Figure 3.5.2-5. Forward Bearing Reaction System Existing Design

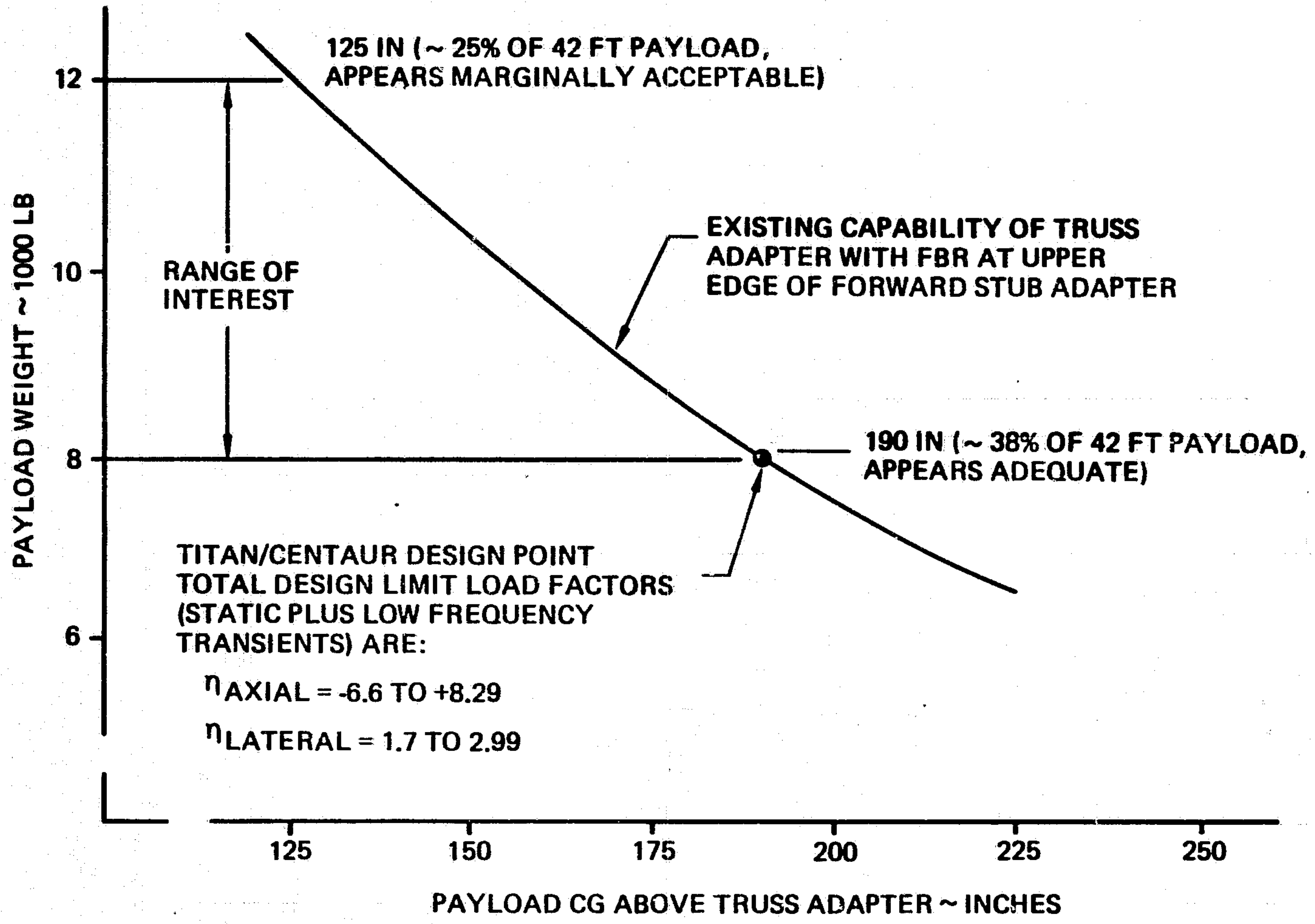


Figure 3.5.2-6. D-IT Truss Adapter Payload Constraints

a 42-ft payload, the foregoing distances range from adequate (190 in) to marginally acceptable (125 in). The use of an FBR at the upper edge of the Centaur stage stub adapter is required to obtain the foregoing payload capabilities.

The airload normal to the shroud versus the allowable FBR limit design load based on the existing FBR design, D-IT strength capability, and T2 strength capability is shown in figure 3.5.2-7. Because an FBR is designed to transfer a sizeable fraction of the airload normal to the shroud, it follows that use of the existing FBR design appears adequate at max q-alpha values under 5000 psf-deg (the probable range of interest for the next level of analysis) but marginal at higher values. (It will be marginal at the higher q-alpha values only if the shroud weight is adversely affected.)

The D-IT fuel tank structural compatibility is shown in figure 3.5.2-8 by indicating, as a function of ultimate equivalent axial load (compression), the pressure differential required across the fuel tank sidewall (lower end). Pressure differential requirements for A3, B3, and B4 vehicle applications, for the structural design max q-alpha condition with FBR = 20,000 lbf, are 17.0, 15.9, and 14.9 psia, respectively. These pressure requirements are achievable within the capability of the current ullage lockup pressure. The ullage lockup pressure required for the D-IT fuel tank is presented in table 3.5.2-5. The ullage lockup pressure requirement derives from the pressure differential required across the fuel tank sidewall (lower end), fuel head pressure, and shroud internal pressure. Ullage lockup pressure requirements for A3, B3, and B4 vehicle applications are 19.1, 20.1, and 20.9 psia, respectively. These pressure requirements are less than the current lockup pressure capability of 23.1 psia.

Titan Stage II (SRB-X Stage 3) Assessment. Structural compatibility of the Titan stage II (T2) for SRB-X application is shown in figure 3.5.2-9. For comparison purposes, the load-carrying requirements at the forward and aft interfaces, for the structural design max q-alpha condition with FBR = 20,000 lbf, are presented for the conditions of an unshrouded stage and a shrouded stage. As indicated, the T2 stage requires shrouding for A3, B3, and B4 vehicle applications to restrict applied loads to acceptable values. (In addition, for B3 and B4 vehicle applications, the T2 stage requires shrouding to effect nearly 100% jettisoning of stage 1 forward cluster structure.)

3.5.2.4 Payload Shroud Weights

Shroud weight data are presented in figure 3.5.2-10. Shroud weights shown for vehicle configurations A3, A4, and B2 reflect a Centaur standard shroud data base, as do the forward shroud sections for vehicle configurations B3, B4, and B6. Aft shroud

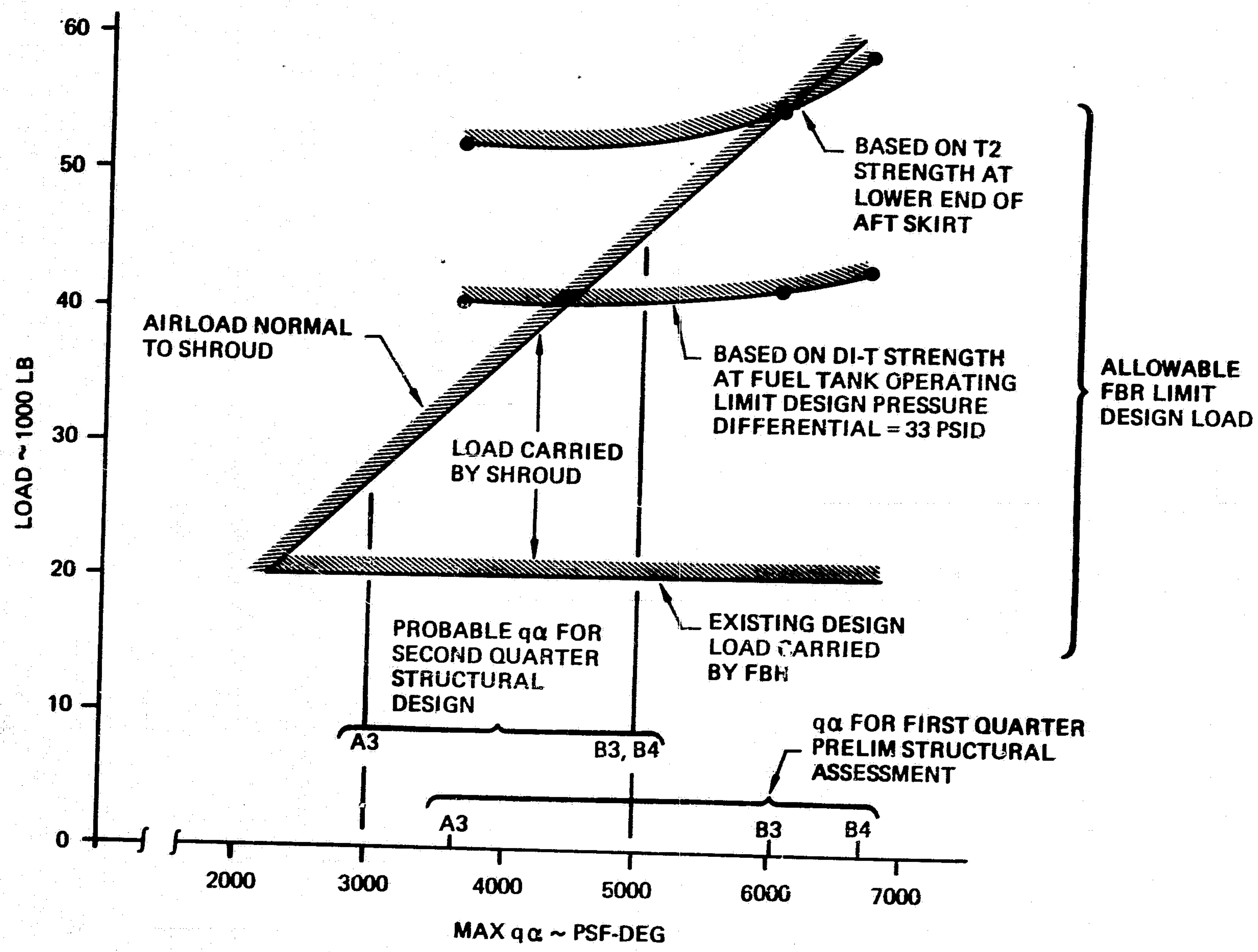


Figure 3.5.2-7. FBR Limit Design Load Considerations

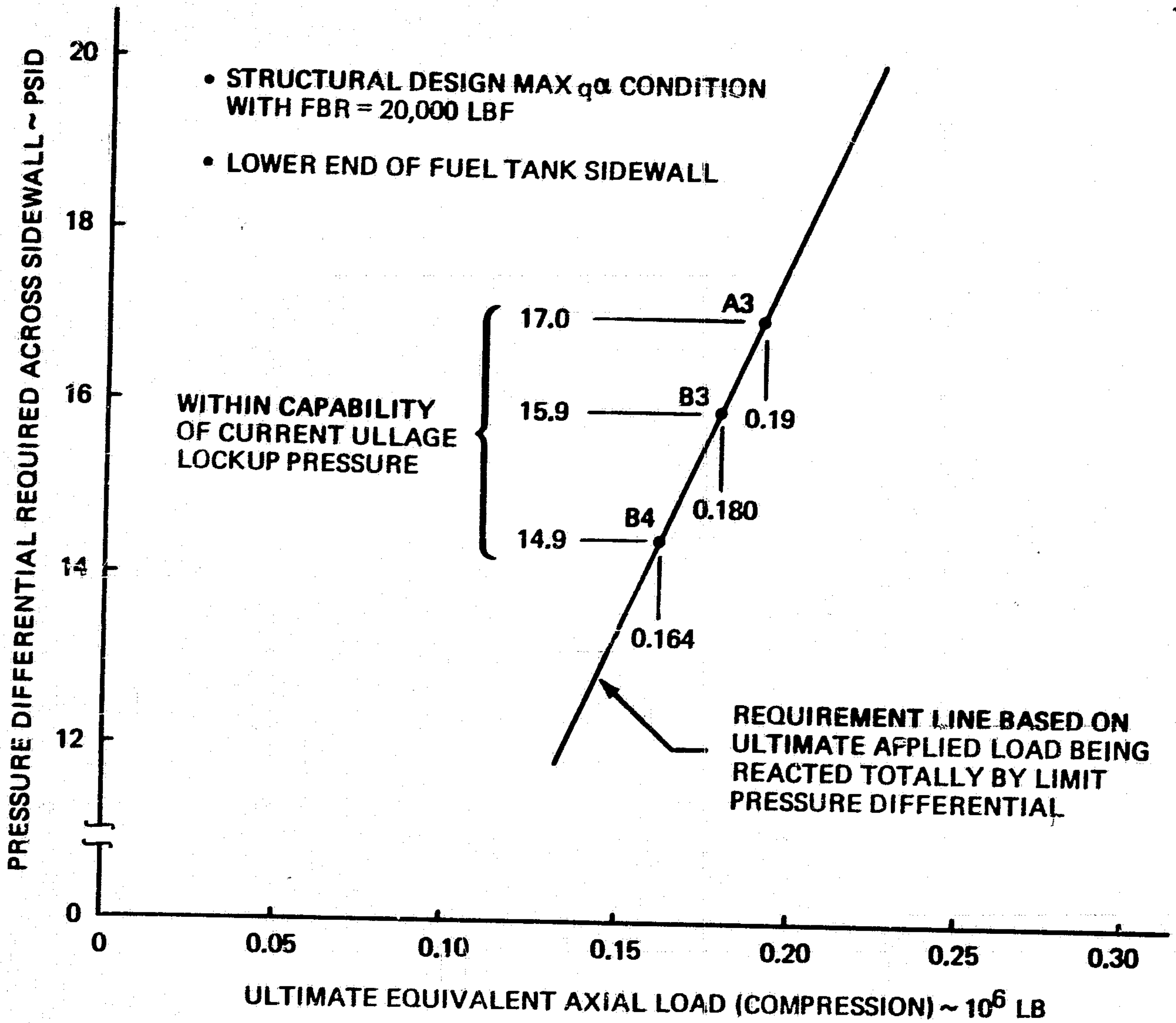


Figure 3.5.2-8. D-IT Fuel Tank Structural Compatibility

Table 3.5.2-5. D-IT Fuel Tank Ullage Lockup Pressure Requirement

ULLAGE LOCKUP PRESS = PRESS DIFFERENTIAL REQUIRED ACROSS SIDEWALL-HEAD PRESS
(REQUIREMENT) + SHROUD INTERNAL PRESS

	A3	B3	B4
PRESSURE DIFFERENTIAL REQUIRED ACROSS LOWER END OF SIDEWALL (PSID)	17.0	15.9	14.5
LESS HEAD PRESSURE (PSIG)	-1.1	-1.0	-0.9
PLUS SHROUD INTERNAL	+3.2	+5.2	+7.3
ULLAGE LOCKUP PRESSURE REQUIRED (PSIA) [1]	19.1	20.1	20.9

COMPARES WITH CURRENT LOCKUP PRESSURE CAPABILITY OF 23.1 PSIA

[1] ESTIMATED AT 1.0 PSIA ABOVE ATMOSPHERIC PRESSURE

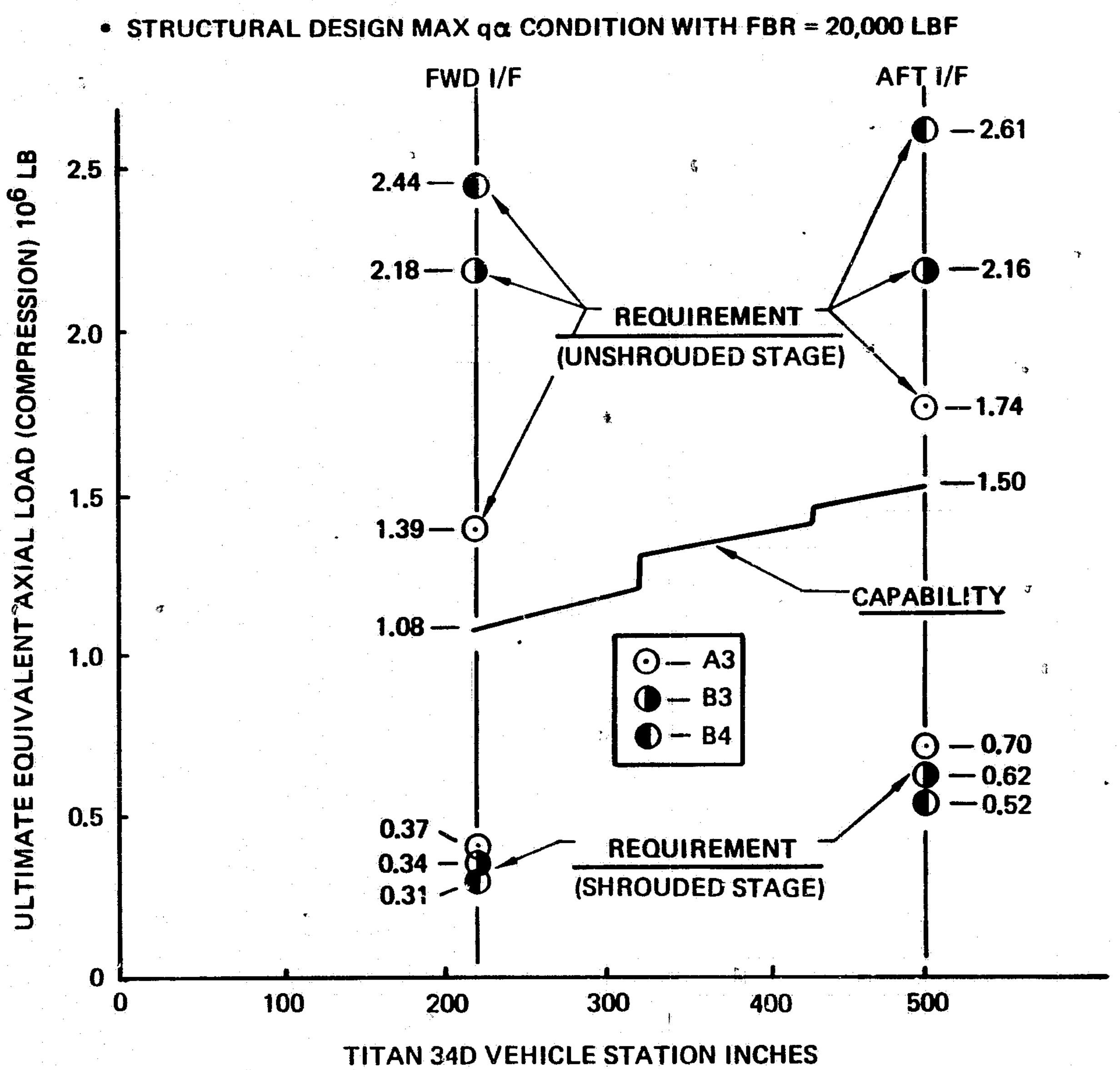


Figure 3.5.2-9. T2 Structural Compatibility

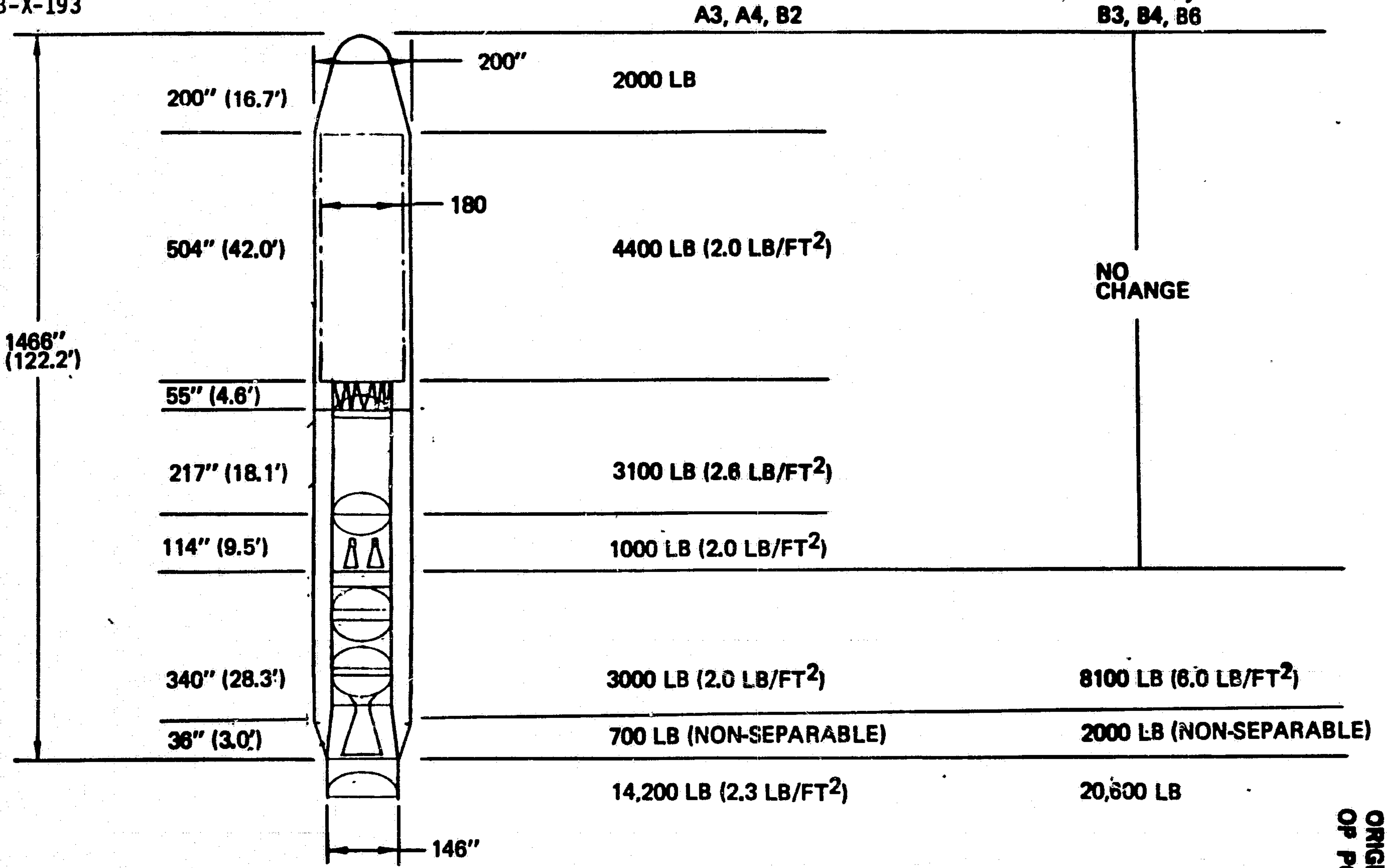


Figure 3.5.2-10. GEO Mission Shroud Weight Estimate

section weights for configurations B3, B4, and B6 are estimated weights reflecting the "interstage" function of the structure.

3.5.3 Performance

Payload capability of the final six concepts was updated to reflect revisions made during the third screening regarding stage performance, weight characteristics, and trajectory parameters such as ideal velocity requirements. Payload capability was determined for LEO, and GEO destinations.

3.5.3.1 Stage and Trajectory Characteristics

The basic ground rules used in the third screening performance analysis are shown in table 3.5.3-1. The ideal velocities associated with each of the concepts are presented in table 3.5.3-2. The variations between concepts for a given destination are the result of differences in thrust-to-weight ratios, particularly for the first stage and the resulting effect on gravity losses.

Table 3.5.3-2. Mission Ideal Velocities

	Mission destination (10^3 fps)		
Concept	LEO	Polar	GEO
A3	29.6	31.3	44.2
A4	29.0	30.5	43.5
B2	29.8	31.1	44.3
B3	29.5	30.8	43.5
B4	29.5	31.1	44.0
B6	29.5	31.0	44.0

Performance and weight characteristics for the stages and vehicle elements are presented in table 3.5.3-3. Relative to charcteristics presented for previous screenings, the indicated characteristics reflect a more accurate definition of the systems in addition to several changes in format. One change is that the interstage between stages 1 and 2 is now shown assigned against the stage 1 interstage rather than as part of the inerts. The second change is the method of calculating the shroud weights, with differences reflecting destination as well as type of vehicle.

Table 3.5.3-1. Performance Ground Rules

- **REFERENCE PARKING ORBIT**

  1. 100 NMI CIRCULAR
  2. 250 FT/SEC RESERVES AND TRIM
  3. ETR LAUNCH AT 90° AZIMUTH
  4. WTR LAUNCH AT 190.5 AZIMUTH (SUN SYNCHRONOUS)

- **GEO SYNCHRONOUS ORBIT**

  1. 14,500 FT/SEC IDEAL VELOCITY ALLOWANCE INCREMENT FROM 100 NMI ETR REFERENCE ORBIT (INCLUDES RESERVES & TRIM)

- **ATMOSPHERE**

  1. 1,962 U.S. STANDARD ATMOSPHERE
  2. ZERO WINDS

- **STAGING**

  1. EXPENDABLE INERTS DROPPED WITH STAGE
  2. SHROUD JETTISONED AT 1 PSF (REF. SHROUD WT ~ 10,000 LB)
  3. NO COAST PHASES

- **PROPULSION**

  1. ACTUAL THRUST TRACE USED ON FIRST STAGE AND COMMON SECOND STAGE (B2)
  2. INITIAL UPPER STAGES USED SQUARE THRUST TRACE, ACTUAL TRACES ARE CURRENTLY IN USE ON B4.

C3

Table 3.5.3-3. Vehicle and Stage Characteristics

APPLI.	STAGE OPTION	PERFORMANCE			WEIGHTS (10^3 LB)			SHROUD WEIGHTS (10^3 LB)			
								LEO/POLAR		GEO	
		THRUST (MLB_F)	ISP (SEC)	BURN TIME	PROP	INERT	INTER-STAGE	BASIC	PER LB	BASIC	PER LB
STRAP-ON	T05(2)	2.35	266	96	850	167.8	—				
STAGE 1 ▷3	4	2.36	267	125	1,107	180.6	5				
	4 (2)	4.72	267	125	2,215	365	15				
	3 (2)	3.43	267	130	1,671	303	13				
STAGE 2 ▷3	1	0.51	293	185	320	61	1.2				
	2	0.93	285	186	610	92	1.2				
	4	2.36	267	125	1,107	165	1.2				
STAGE 3	T2	0.10	318	208	66	8.5	0.9	5/10 ▷1	.097	—	.097
	T2S	0.10	318	339	107	9.6	0.9	5/10	.097	—	.097
	S1	0.40	304	110	96	13.0	0.9	5/10	.097	—	.097
STAGE 4	C	0.03	444	444	30	4.9	—	—	—	9.1/14.2 ▷2	.097

INERT WEIGHT DIFFERENCES FOR FWC

STAGE 1	4	ALL OTHER PARAMETERS ARE SAME	142
	4 (2)	ALL OTHER PARAMETERS ARE SAME	288
	3 (2)	ALL OTHER PARAMETERS ARE SAME	250
STAGE 2	1	ALL OTHER PARAMETERS ARE SAME	50
	2	ALL OTHER PARAMETERS ARE SAME	71
	4	ALL OTHER PARAMETERS ARE SAME	127

▷1 5 FOR A3, A4, B2 VEHICLES; 10 FOR B3, B4, B6 VEHICLES

▷2 9.1 FOR A3, A4, B2 VEHICLES; 14.2 FOR B3, B4, B6 VEHICLES

▷3 INERTS REFLECT STEEL CASE SRM

3.5.3.2 Payload Capability

LEO performance capability is shown in figure 3.5.3-1. The requirements for this mission are judged to be the least definitive of the three destinations investigated. There does appear to be some merit, however, in the ability to launch IUS-class payloads since this upper stage will be used at least up through the late 1980's. Growth versions of the IUS which could place 7000 lb in GEO from LEO would require a delivery capability to LEO of approximately 45,000 lb. Should the same system be delivered by an STS, the launch weight would be approximately 51,000 lb with the difference being in the airborne support equipment (ASE). Performance capabilities for the three-stage configuration options are presented for both steel and filament wound case motors. Several vehicles (B3, B4 with T2S, and B6) satisfy the early IUS requirements even when using steel cases. Essentially all concepts satisfy the growth IUS when FWC's are used. Also indicated is the payload capability of the B3 using four stages. Operating in this mode and with FWC's, the B3 could deliver approximately 62,000 lb to LEO.

Polar capability comparisons are shown in figure 3.5.3-2. It should also be noted that the indicated capability is for Sun synchronous orbit rather than polar at $i = 90$ deg. Accordingly, for $i = 90$ deg, add 1500 lb to the indicated payload. The assumed 1987-90 payload requirement of 30,000 lb is judged to provide the same effective payload as the STS 32,000-lb requirement with the difference associated with the ASE. The additional 5000 lb for the 1991-95 time period was judgmental. Again, it should be noted that the A3 and B4 configurations require a stretch T2 in order to be competitive. Several configurations (B3, B4, B6) can nearly satisfy the far-term requirement using steel cases; and with FWC, they can approach 40,000 lb into a polar orbit.

GEO performance capability is shown in figure 3.5.3-3. All performance assumes a standard Centaur D-IT (W_p = 30,000 lb) as the fourth stage. It should also be noted, the indicated capability does not reflect performance optimization for any stage in the vehicle but does include a trajectory for each configuration which has reasonable gravity losses and maximum dynamic pressure characteristics. The early time frame performance goal is greater than that assumed for the growth IUS and the 1990-95 value corresponds to STS/Centaur capability.

All options evaluated exceed the 1987-90 performance goals even when using steel SRM cases. Several options (B3, B4, B6), when using FWC SRM's, exceed the later time frame performance goals and approach a GEO delivery capability of 13,000 lb. Further performance optimization, particularly in the area of second-stage optimization, is expected to increase the value to nearly 15,000 lb.

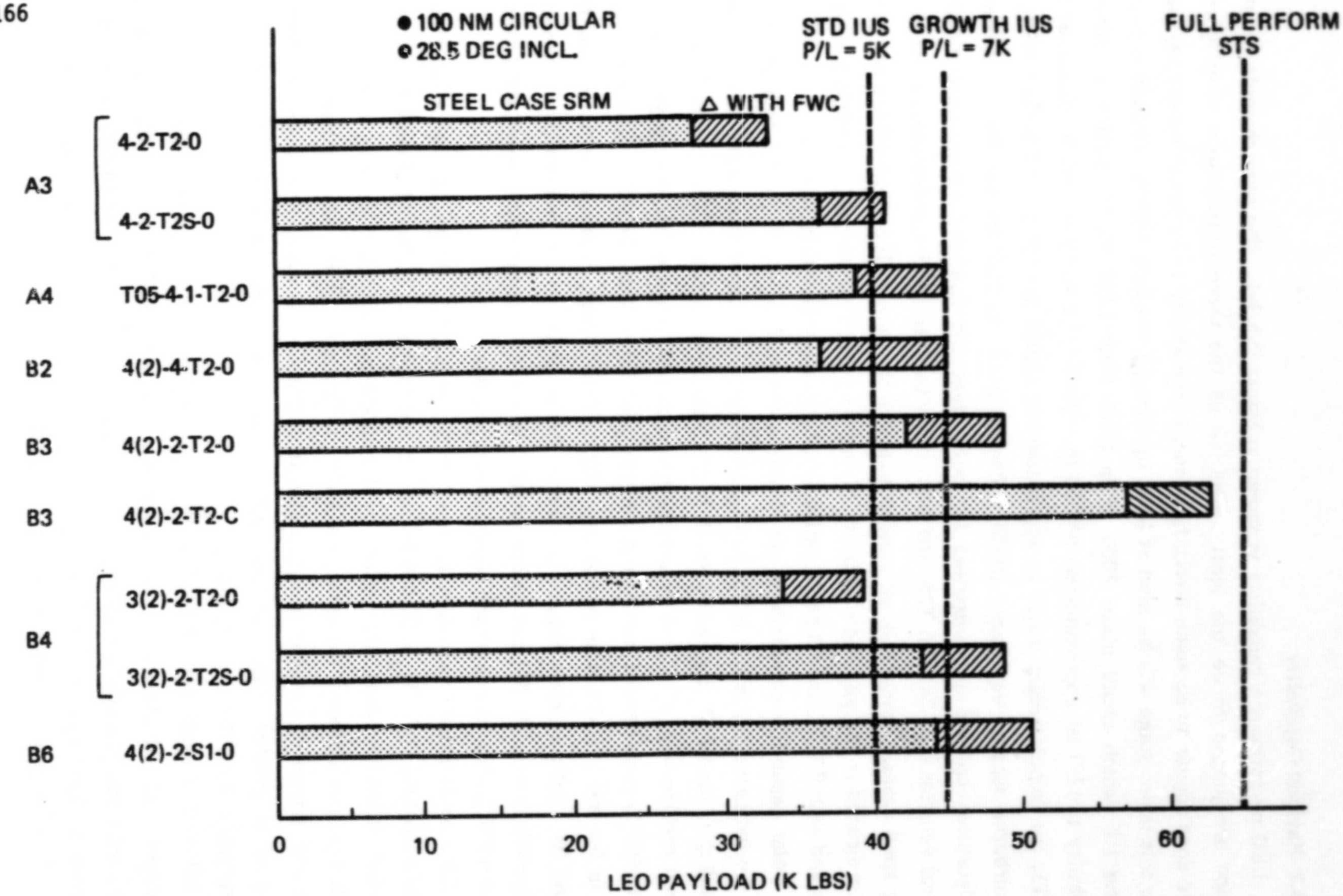


Figure 3.5.3-1. LEO Performance Comparison

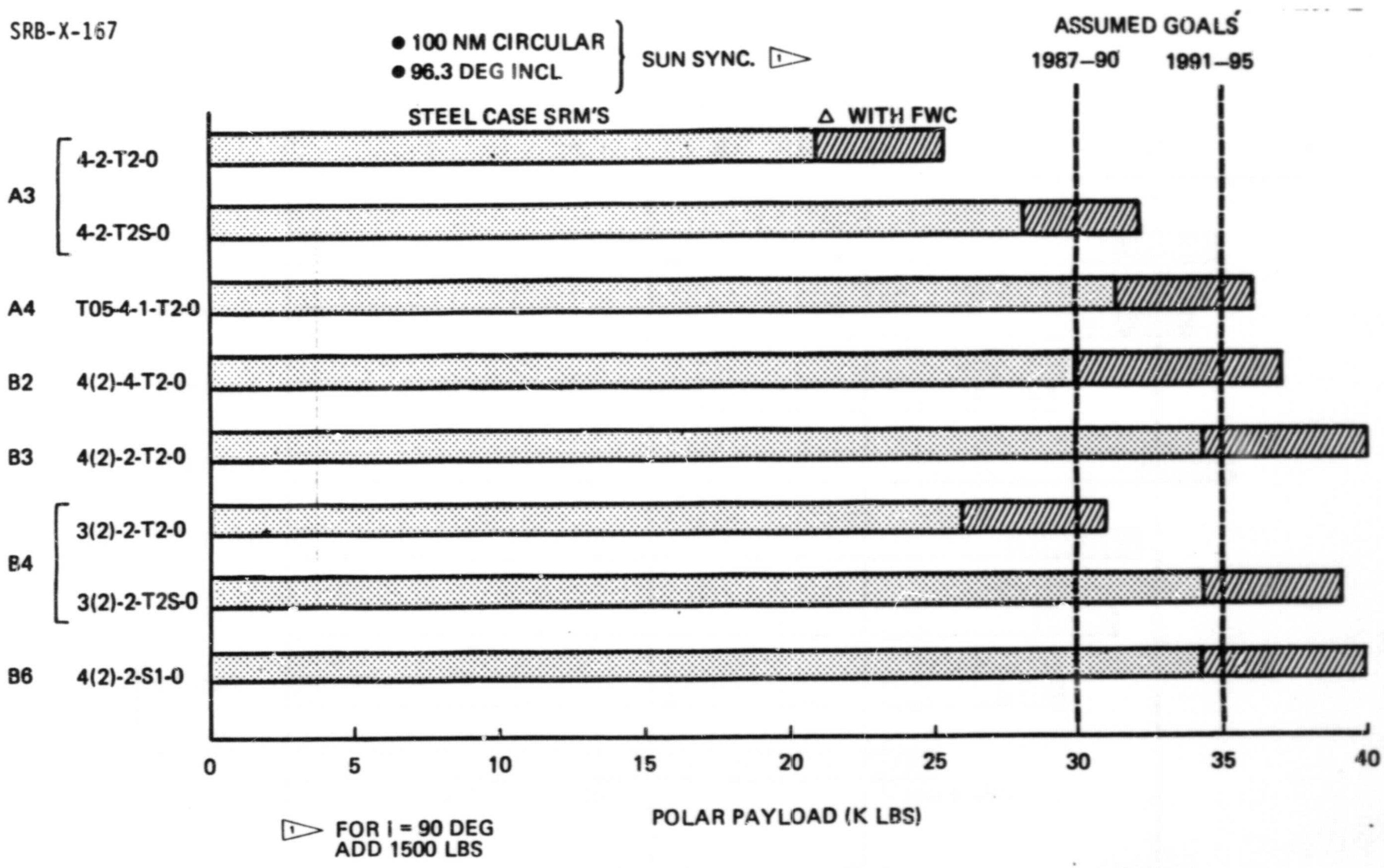


Figure 3.5.3-2. Polar Performance Comparison

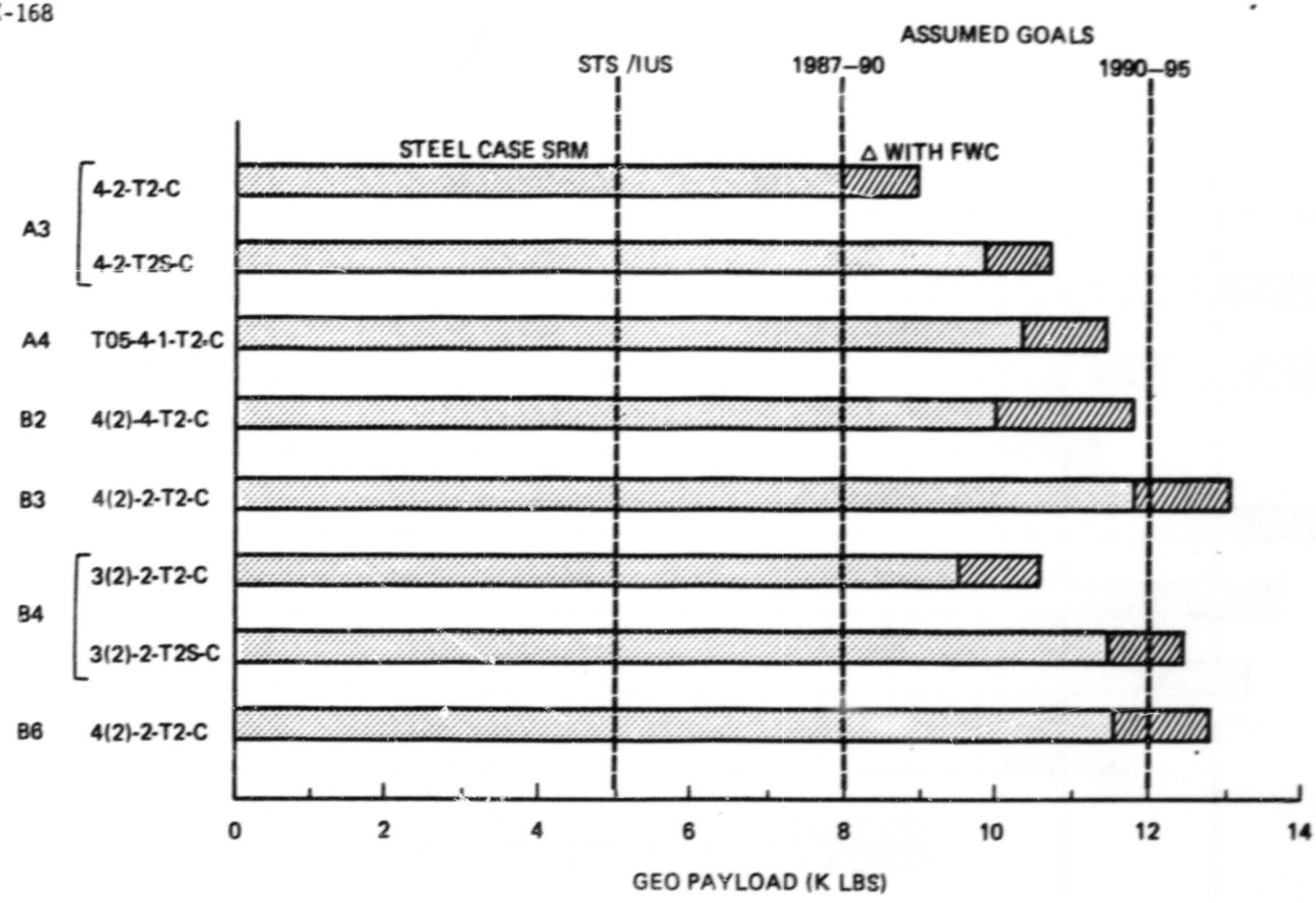


Figure 3.5.3-3. GEO Performance Comparison

3.5.4 Stability and Control

The stability and control analyses investigated several areas: (1) static stability in pitch and yaw, (2) dynamic rigid stability in pitch, and (3) need for load alleviation. For the most part, these assessments were made against the A3, B3, and B4 configurations as they were judged to be the most challenging from a stability and control standpoint.

3.5.4.1 Static Stability

Static stability was measured by the margin or ratio of the torque capability from the thrust vector control (TVC) to the torque caused by wind disturbances. Comparison of the pitch static stability of the configurations is shown in table 3.5.4-1. The B4 configuration margin falls below the preliminary target because of its short thrust vector moment arm. The yaw static stability comparison is shown in table 3.5.4-2 for the class B vehicles. Values for class A vehicles are the same as for pitch since they involve a single booster for the first stage. The data indicate that yaw margin appears marginally acceptable for the B configurations; but it should be noted that the pitch and yaw assessment at this time does not include any load alleviation, which would considerably reduce the dynamic pressure.

3.5.4.2 Rigid Body Dynamic Simulation

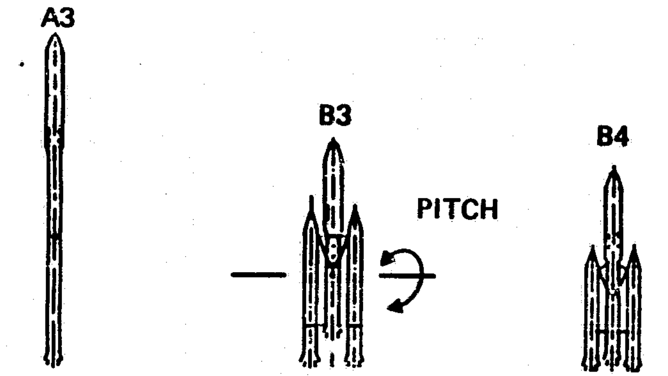
The rigid body dynamic simulation assessed, in a real-time sense, whether the control system can follow the commanded flightpath angle and overcome the disturbance. Comparison of the three vehicles is presented in table 3.5.4-3, while figure 3.5.4-1 shows the time simulation history of the A3 and B3 vehicles. Assuming a factor of 4 between the first mode bending frequency and the control frequency indicates the A3 configuration shows significant flightpath errors because of the low bending frequency and resulting slow responsiveness of the control system.

TVC requirements for the B4 are more demanding because of its relatively short moment arm. Figure 3.5.4-2 indicates over 60% of the gimbal capability must be used to provide the necessary control, whereas 50% was the desired goal.

3.5.4.3 Other Observations

Although a flexible body analysis has not been performed, an observation can be made relative to vehicles with high length-to-diameter ratios. Historically, the vehicles tend to present significant challenges because their control systems have to provide active damping rather than the structures providing passive damping from their own stiffness. Accordingly, the class A vehicles are viewed as undesirable from a stability and control standpoint.

Table 3.5.4-1. *Pitch Static Stability Assessment*

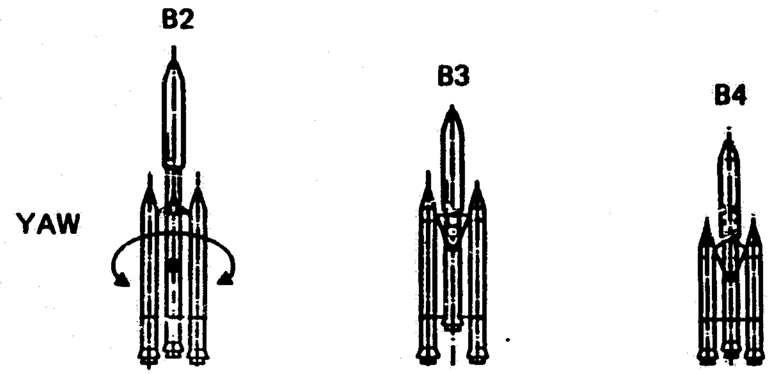


	A3	B3	B4
MAX Q DYNAMIC PRESSURE * (PSF)	515	800	715
V_{WIND} (FT/SEC) *	230	260	200
$V_{VEHICLE}$ (FT/SEC)	1454	1362	1093
CP-CG (FT)	79	33	34
GIMBAL PLANE - CG (FT)	113	68	46
INDUCED α (DEG)	7.13	10.08	10.19
MARGIN TVC/WIND TORQUE	5.24	3.04	1.76
δ TO BALANCE (DEG)	.9	1.56	2.70

* DATA TAKEN AT MAX Q
WIND DATA 95% WITH GUST OF 50 FPS

δ = GIMBAL ANGLE

Table 3.5.4-2. *Class B Yaw Stability*



	B2	B3	B4
MAX Q DYNAMIC PRESSURE (PSF) *	495	800	715
V_{WIND} (FT/SEC) *	260	260	200
$V_{VEHICLE}$ (FT/SEC)	1159	1362	1093
CP-CG (FT)	84	66	58
GIMBAL PLANE-CG (FT)	65	68	46
INDUCED α (DEG)	12.42	10.08	10.19
TVC STABILITY MARGIN	2.76	2.34	2.20
GIMBAL ANGLE TO BALANCE (DEG)	1.72	2.02	2.16

* DATA TAKEN AT MAX Q
WIND DATA 95% WITH GUSTS OF 50 FPS

Table 3.5.4-3. Rigid Body Trim Condition Summary

SIMULATION PROVIDES INSIGHT INTO SRB-X PITCH CONTROL REQUIREMENTS

	A3	B3	B4
DAMPING RATIO	0.77	0.77	0.77
CONTROL FREQUENCY (HZ)	0.15	0.80	0.86
MAX $q-\alpha$ (PSF-DEG)	3,672	8,600	7,286
MAXIMUM FLIGHT PATH ERROR	-4.15°	-1.5°	-2.28°
GIMBAL FREEDOM REQUIRED *	1.72°	1.71°	2.93°
GIMBAL RATE REQUIRED *	0.62°/S	-1.50°/S	-1.35°/S

* TVC CAPABILITY = 4.75° AND 3.0°/SEC

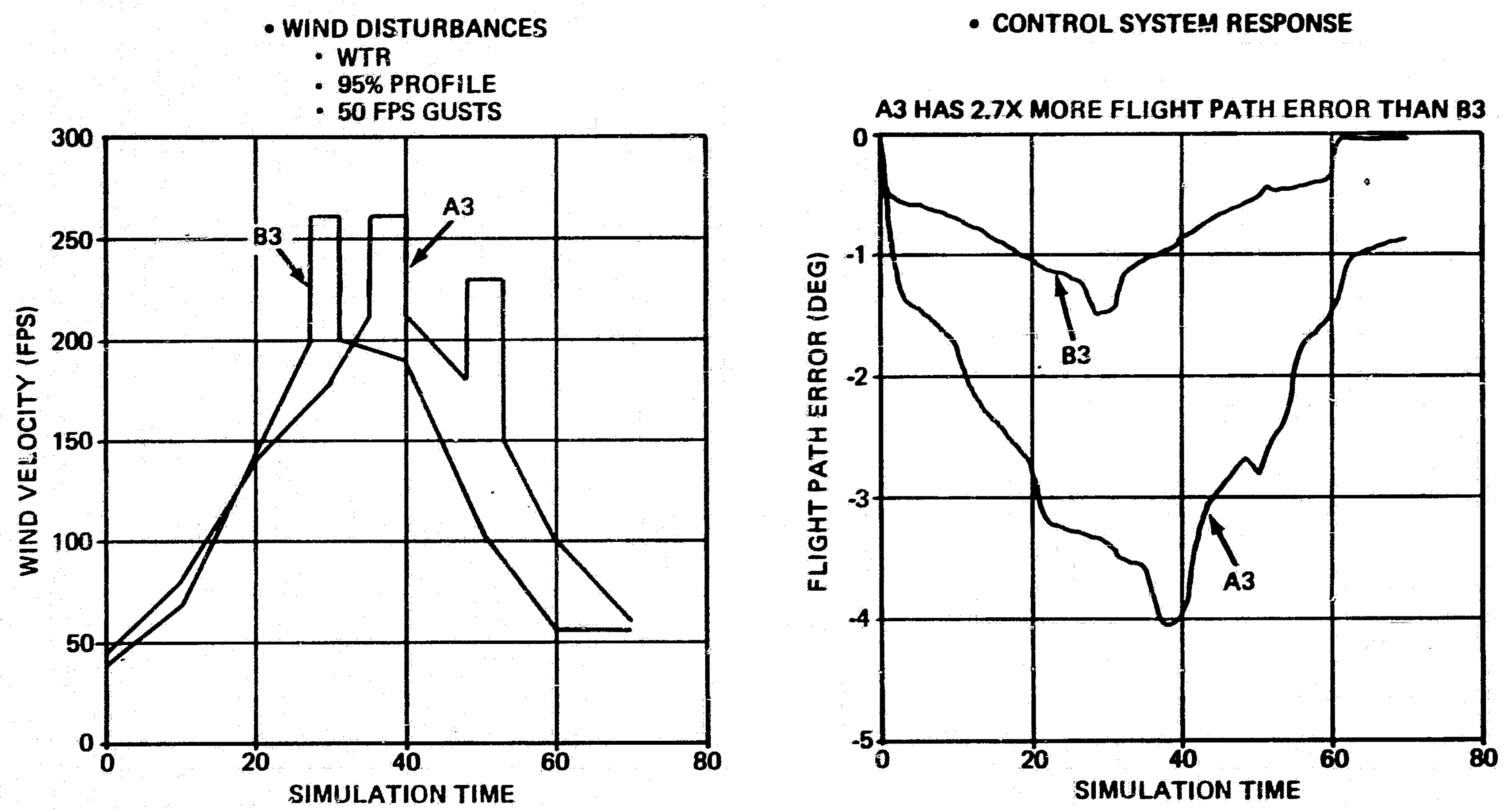
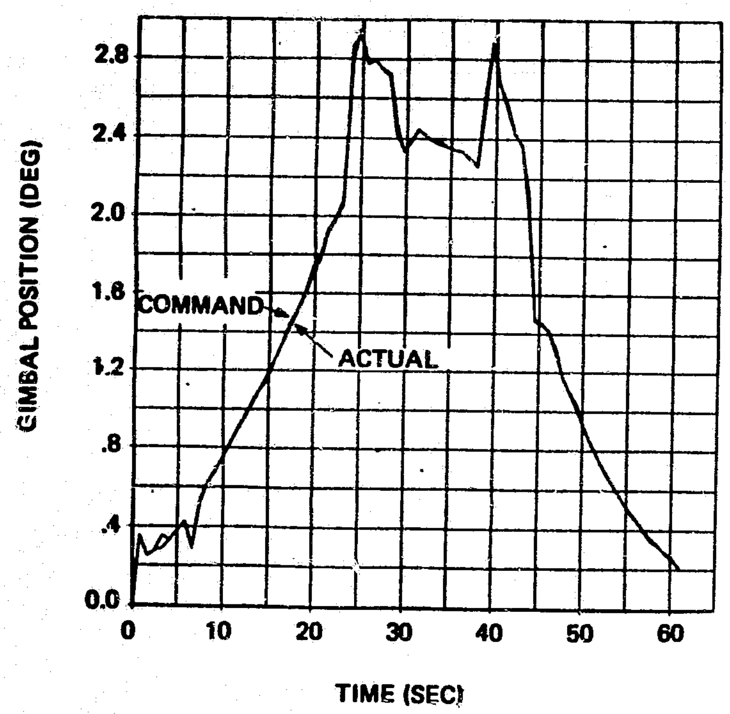
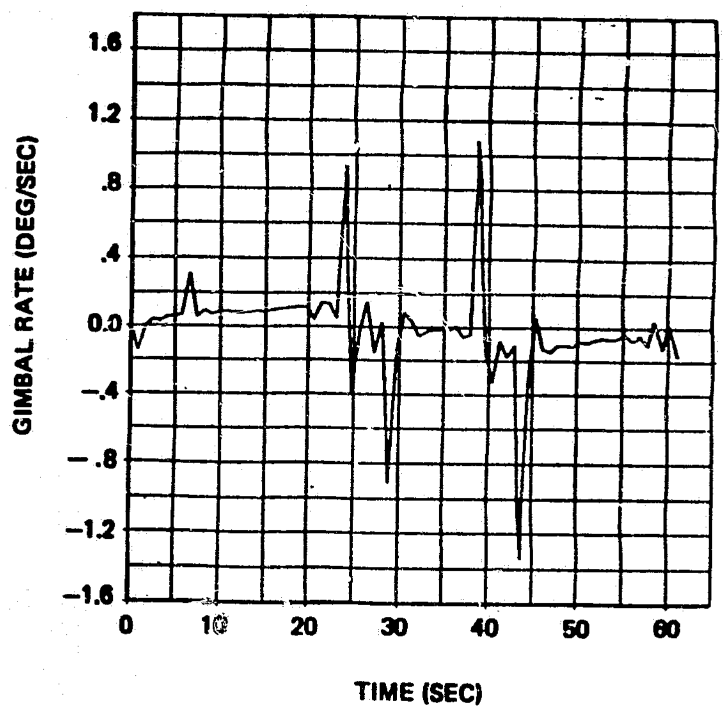


Figure 3.5.4-1. Rigid Body Dynamic Simulation Results

● B4 CONFIGURATION



AVAILABLE GIMBAL POSITION = 4.75 DEG



AVAILABLE GIMBAL RATE = 3 DEG/SEG

Figure 3.5.4-2. TVC Requirements and Capability

3.5.5 Facilities Analysis

The facility analysis up through the third screening had three major objectives: to (1) identify the facility requirements associated with each of the final six configurations, (2) assess the applicability of candidate launch facilities, and (3) assess the impact of each configuration at the selected launch facility.

3.5.5.1 Requirements

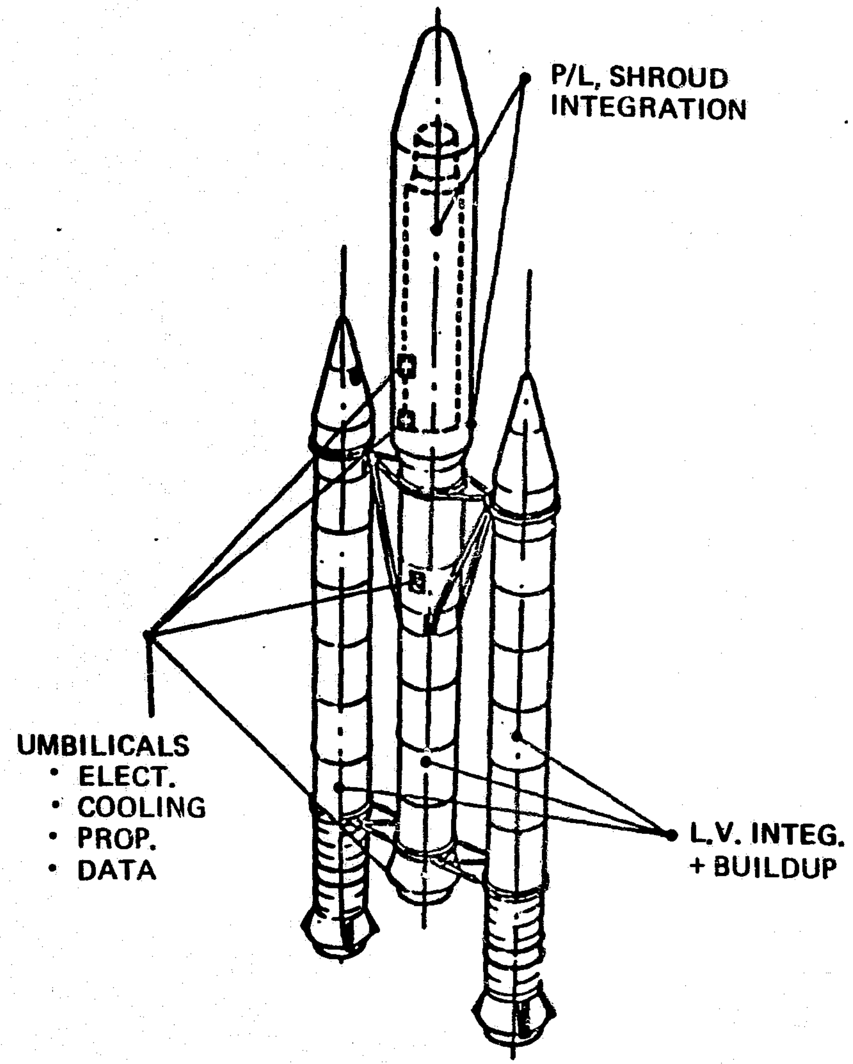
The types of facility requirements identified for each configuration are indicated in figure 3.5.5-1. Propellant umbilicals are required for stage 3 (N_2O_4/Aero-50) and stage 4 (LO_2/LH_2). All stage elements require electrical and data interfaces with the facilities. Integration of the payload with shroud and attachment to the launch vehicle presents a requirement considerably different from the STS. Changeout or removal of the payload at the pad is also viewed as a desirable feature. The height of the vehicle and its various elements influences the servicing platforms used during assembly and at the launch pad. The GLOW of each vehicle is used to assess the ground transportation system used to move the vehicle from an assembly area to launch pad.

3.5.5.2 Facility Selection

The second facility task was to assess the applicability of Titan, STS, or other facilities for use by the SRB-X beginning in 1987-88. A summary assessment of the facility options, as well as major needs imposed by the configurations, is presented in table 3.5.5-1. The Titan facilities at WTR were found unacceptable due to scheduling constraints, while those at ETR were severely limited in terms of capability and provisions. In summary, use of Titan facilities at ETR and WTR does not appear to be compatible with the SRB-X requirements.

Use of STS facilities appears to be the most promising. At WTR, use of SLC-6 also presents some rigid schedule constraints in terms of not jeopardizing the first STS launch. Several configurations, (B4, B3, and B6) do have height characteristics that would allow use of existing servicing and assembly facilities. The other configurations required more extensive modifications. STS facilities at ETR offer more flexibility because of the availability of a second launch pad (LC-39B). All configurations could be accommodated with varying degrees of modification to the fixed service structure (FSS).

Other facilities considered were those associated with Saturn I and IB launches. At this time, all that would be useful is the land, so these were ruled out from further consideration.



PHYSICAL CHARACTERISTICS

CONFIGURATION	HEIGHT (FT) FOR WTR	GLOW (M LBS)
A3	330	2.1
A4	280	2.8
B2	240	4.0
B3	205	3.4
B4	195	2.8
B6	205	3.4

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Figure 3.5.5-1. Facility Requirements

Table 3.5.5-1. *Ground Facility Assessment*

TITAN FACILITIES	COMMENTS
• WTR (SLC-4W) (SLC-4E)	• VEHICLE CHARACTERISTICS EXCEED FACILITY CAPABILITIES • LAUNCH SCHEDULE THROUGH 1988 PRECLUDES MODIFICATIONS
• ETR (ITL & LC-41)	• LIMITED AREA IN SMAB • TRANSPORTER(S)/CRAWWAY CAPABILITY EXCEEDED • NEW SERVICE TOWERS EXCEPT FOR B3,B4,B6 • NEW FLAME DUCTS REQUIRED
✓ **STS FACILITIES**	
• WTR (SLC-6)	• OCT 1985 IOC CANNOT BE JEOPARDIZED • 18 MONTH GAP BETWEEN 1ST AND 2ND LAUNCHES • B4 FITS. B3 AND B6 OKAY WITH MINOR VEHICLE MODIFICATION OR NOSE CONE INSTALL. WITH AUX. CRANE • A3, A4 & B2 REQUIRE NEW MST & EXCAVATION AND A4 ALSO A NEW LAUNCH MOUNT
• ETR LC-39B VAB (CELL 4) MLP (1)	• MID 1986 IOC FOR 39B CANNOT BE JEOPARDIZED • B2, B3, B4 AND B6 ARE FSS COMPATIBLE ALTHOUGH A NEW 50 TON CRANE IS REQUIRED FOR PAYLOAD CHANGEOUT • A3 AND A4 NEED ADDITIONAL FSS HEIGHT • VAB CELL (1) AND MLP REQUIRE MINOR MODIF.
OTHER	
• LC34 OR 37B OR ALL NEW	• ONLY LAND IS AVAILABLE • NOT NECESSARY UNLESS BACKUP SITE IS NECESSARY OR SCHEDULE BECOMES A PROBLEM

✓ SELECTED APPROACH

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3.5.5.3 Facilities Impact Assessment

A discussion of the impact of each of the six configurations on STS facilities at KSC and VAFB follows.

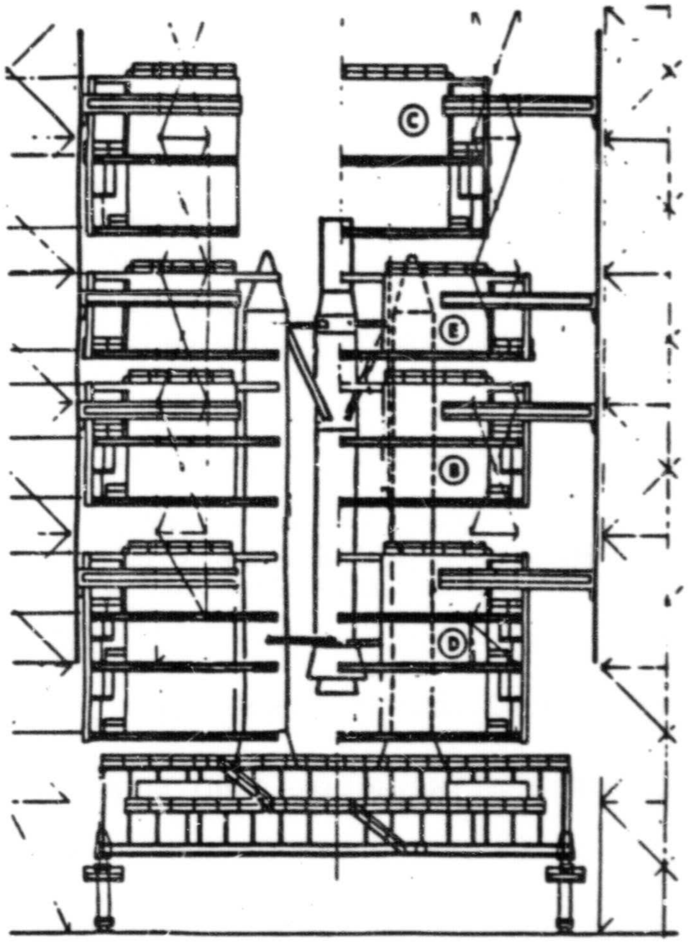
KSC Facilities. The principal facilities investigated for impact were the vehicle assembly building (VAB), mobile launcher platform (MLP), and the pad.

It has been assumed that VAB high bay (HB)-4 would become available for SRB-X stacking. ET processing would be done in HB-2 and STS processing in HB-1 and HB-3. The primary difference between the six configurations in this area is that of the access platforms required to complete assembly and checkout, as indicated in figure 3.5.5-2. Due to their height, configurations A3 and A4 are the most demanding.

The MLP supports the vehicle from the time of assembly start until launch. The impact of the configurations on the MLP is presented in table 3.5.5-2. All configurations require new umbilical provisions. Because the A4 has three SRM's burning at liftoff, a new flame hole will be required. The outside SRM's for A4 (strapons) as well as the parallel burn motors for the B configurations are located in the same position as for the shuttle. All B configurations will require a pedestal to allow the stacking of the core.

Launch complex (LC) 39B has been assumed to support SRB-X as well as the STS. The goal was not to have any modifications to preclude the IOC of 1986 for this LC. The facilities of concern at the pad include the FSS and rotating service structure (RSS). Comparison of configurations for impact on these facilities is shown in table 3.5.5-3. Again, vehicle height becomes the key factor in differences regarding increases in the height of the FSS. Vehicle height also contributed to differences between vehicles regarding the location of umbilicals for payload access and hypergol servicing. Common features that are variations from the current facilities include the need for a new crane and umbilicals for servicing the payload and Centaur.

VAFB Facilities. The launch complex to be used is SLC-6, which is the same as that used by the STS. Principal facilities considered at this launch site included the mobile service tower (MST), launch mount (LM), and access tower (AT). The comparison of configurations for their impact on these facilities is presented in table 3.5.5-4. Again, vehicle height is the main factor, which results in differences in the degree of impact. In this case, the problem is so severe that configurations A3, A4, and B2 are rejected because of constraints imposed by the MST in terms of height modifications. These modifications are viewed as impossible due to scheduling conflicts with the STS operations. Due to cost, a new MST also appears to be out of the question.



● NEW ACCESS PLATFORMS:

EXIST. PLATFORMS REQ'D \ CONFIG. / HT	A3 (316')	A4 (284')	B2 (242')	B3/B6 (204')	B4 (184')
D	✓	✓	✓	✓	✓
B	✓	✓	✓	✓	✓
E	✓	✓	✓	✓	✓
C	✓	✓	✓		
ADDITIONAL ACCESS PLATFORM ABOVE PLATFORM : "C"	✓	✓			

1 TOP OF PAYLOAD

● NEW CRAWLERWAY

● RELOCATE E.T. CHECKOUT CELLS

ACCESS PLATFORMS ARE THE DIFFERENTIATOR

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Figure 3.5.5-2. Access Platform Usage

Table 3.5.5-2. MLP Impact

<u>A3:</u>

- REINFORCE SRB SUPPORT HAUNCHES TO HANDLE INCREASED MOMENTS FROM WIND LOADS
- ADD T-O UMBILICAL RECEPTACLE AT AFT SKIRT (11.363" ABOVE MLP DECK)

<u>A4:</u>

- FLAME HOLE MODIFICATIONS SIMILAR TO THOSE FOR SHUTTLE ENHANCEMENT OPTION 4 EXCEPT FOR CENTER SRB SUPPORTS FOR CORE STAGE AND RELOCATED STRAP-ON SUPPORT POINTS
- ADD T-O UMBILICAL RECEPTACLE AT CORE AFT SKIRT (11.363" ABOVE MLP DECK)

<u>B2, B3, B4, B6:</u>

- REINFORCE MLP COMPARTMENT 38 STRUCTURE AREA TO SUPPORT STACK OF CORE VEHICLE
- ADD CORE SRB SUPPORT PEDESTAL AT INDICATED HEIGHT ABOVE MLP DECK (INCHES)

B3	B2	B4
324.05	79.73	95.37

- ADD T-O UMBILICAL RECEPTACLE AT CORE STAGE AFT SKIRT

Table 3.5.5-3. FSS and RSS Impact Comparison

IMPACT AREA \ CONFIGURATION	A3	A4	B2	B3/B6	B4
FSS TOWER HEIGHT INCR (FT)	60' (3 BAYS)	40' (2 BAYS)	NONE	NONE	NONE
FSS TOWER HAMMERHEAD HOIST CRANE TO 50 TON CAPACITY	X	X	X	X	X
INCREASE TOWER STRENGTH TO ACCOMMODATE UPRATED CRANE AND INCREASED HEIGHT (IF REQUIRED)	X	X	X	X	X
ADD CENTAUR SERVICING TO FSS	X	X	X	X	X
ADD CENTAUR T-O UMBILICAL(S) TO FSS	X	X	X	X	X
ADD PAYLOAD SERVICE UMBILICAL TO FSS (T-O)	X	X	X	X	X
ADD PAYLOAD ACCESS ARM					
FSS	X	X			
RSS			X	X	X
ADD HYPERGOL UMBILICAL FOR T2 STAGE					
FSS	X	X			
RSS			X	X	X

• TOWER HEIGHT IS THE DIFFERENTIATOR

Table 3.5.5-4. *WTR STS Facilities (SLC-6) Assessment*

FACILITY AREA	A3	A4	B2	B3 AND B6	B4
LAUNCH MOUNT	POSSIBLE STRUCTURE MODIFICATIONS FOR WIND LOADS	REJECT: INCOMPATIBLE DUE TO BOOSTER SPACING	OK	OK	OK
MOBILE SERVICE TOWER	REJECT: NEW MST REQUIRED	REJECT: NEW MST REQUIRED	REJECT: NEW MST REQUIRED	INVESTIGATE VEHICLE RE-CONFIG	OK WITH MODIFICATIONS TO WORK STANDS
ACCESS TOWER	USABLE WITH MODIFICATIONS	USABLE WITH MODIFICATIONS	USABLE WITH MODIFICATIONS	USABLE WITH MODIFICATIONS	USABLE WITH MODIFICATIONS

HEIGHT, USE OF STRAP-ONS ARE THE DIFFERENTIATORS

- REJECT A3, A4, B2 FOR USAGE AT SLC-6
- INVESTIGATE B3 RE-CONFIGURATION IN 2ND QUARTER
- DETERMINE B4 MODIFICATION IMPACT: MST, ACCESS TOWER
- PAYLOAD PROCESSING MAY BE A PROBLEM AREA

Configurations B3 and B6 are taller than the current capabilities of the MST; but both are judged to have the potential for reduction by approximately 10 ft, thus becoming compatible.

Access platforms and umbilical needs are similar to those required at KSC. These provisions would be incorporated in the MST and AT.

In summary, facilities are a differentiator for SRB-X at WTR—to the extent that concepts A3, A4, and B2 are not compatible. Remaining concepts B3, B4, and B6 can be accommodated at both KSC and VAFB with straightforward modifications of existing STS facilities on a noninterference basis with STS operation.

3.5.6 ROM Cost

Although a complete estimate of development cost for each configuration was not scheduled for the first quarter, a preliminary estimate was made in terms of differences concerning the SRM's and facilities. The following paragraphs present the cost data concerning each area, as well as total impact on each vehicle.

3.5.6.1 SRM Cost

To support identification of concept differences, preliminary estimates were made for each SRM in terms of DDT&E and unit cost, with the results shown in table 3.5.6-1. The DDT&E cost is strongly influenced by the number of qualification firings required to verify performance and the amount of propellant required for each firing. Those SRM's indicated as requiring three firings have different burn times and/or a different operating environment relative to the standard SRM. Five firings are suggested for motors that also incorporate new nozzles. The other aspect of the DDT&E cost is that associated with the basic design and analytical effort required for each SRM. A summary of the basic design effort and/or extent of modifications or new hardware is presented in table 3.5.6-2.

Unit cost reflects the time period of 1988, when approximately 100 STS will have been flown, which means approximately 200 four-segment SRM's have been loaded and up to 30 hardware units have been produced. The S1 unit cost assumes the MX is in full-scale production.

3.5.6.2 Facility Modification Cost

KSC facility modification costs for all six configurations are compared in table 3.5.6-3. The impact of the additional height of the A3 and A4 configurations is the major contributor to their greater cost. Facility costs associated with VAFB are shown

Table 3.5.6-1. SRM ROM Cost Trends

SRB-X-170

- IN MILLIONS (1982 DOLLARS)

MOTOR	STAGE APPLICATION	DDTE TEST FIRINGS	DDTE COST	UNIT COST	
4 SEG.	1	0	1	12.2	1
4 SEG.	2	3	45	12.7	1
3 SEG.	1	3	38	10.5	1
2 SEG.	2	5	60	9.8	1
1 SEG.	1	5	46	7.5	1
S1 (MX TYPE)	3	5	30	3.3	2

1 INCLUDES NEW STEEL CASES AND PROPELLANT
ASSUMES 100 STS MOTORS HAVE BEEN LOADED

2 KEVLAR CASE AND PROPELLANT. MX IN PRODUCTION

Table 3.5.6-2. Existing Design Use Summary

1. STS SRM CASE COMPONENTS
2. STS SRM CASTING SEGMENTS
3. STS SRM IGNITER
4. STS SRM NOZZLE
5. STS SRM PROPELLANT GRAIN CONFIGURATION
6. PROPELLANT BURN RATE TAILORING
7. STS SRM GRAIN INHIBITOR DESIGN
8. STS SRM MOTOR INSULATION DESIGN

	1	2	3	4	5	6	7	8
STD 4-SEG SRM 1ST STAGE	E	E	E	E	E	E	E	E
4-SEG SRM 2ND STAGE	E	E	E *	E	E *	M	M	M *
3-SEG SRM 1ST STAGE	E	E	E *	E	E	M	E *	E *
2-SEG SRM 2ND STAGE	E	E	N	N	M	M	M	M
1-SEG SRM 3RD STAGE	E	N	N	N	M	M	M	M
S-1 SRM ⊳ 3RD STAGE	E	E	M *	N	E *	N	N	N

* = ANALYSES WILL DETERMINE IF CHANGE IS NEEDED

E = USES EXISTING CONFIGURATION

M = REQUIRES MODIFICATION

N = NEW DESIGN MAY RETAIN SOME COMPONENTS OF EXISTING DESIGN

⊳ S-1 COMMENTS ARE RELATIVE TO FIRST STAGE MX MOTOR

Table 3.5.6-3. KSC STS Facility Impact Cost Assessment

IMPACT AREA		VEHICLE CONFIGURATION					
		A3	A4	B2	B3	B4	B6
VAB		22.0	22.5	18.0	16.0	16.0	16.0
CRAWLER		2.0	–	–	–	–	–
MLP		10.0	11.7	4.0	3.0	3.0	3.0
PAD	FSS	43.5	42.5	35.5	35.5	35.5	35.5
	RSS	1.0	1.0	7.0	7.5	7.0	2.5
TOTAL		78.5	77.7	64.5	62.0	61.5	57.0

NOTE:
- INCLUDES DESIGN COSTS; NO CONTINGENCY
- COST IN M$

in table 3.5.6-4. As indicated earlier, three of the six configurations were judged unacceptable. No appreciable differences are seen among the remaining configurations.

3.5.6.3 Vehicle Level Cost

The combination of the SRM and facility cost, as applied to each of the six final configurations, is presented in table 3.5.6-5. The A4 vehicle indicates the least cost in terms of stage differences because only one motor requires development. The most expensive vehicle to develop is the B4 because it has one new SRM and two modified stages.

STS facility costs indicate a minimum of differences at ETR. At WTR, if the A3, A4, and B2 configurations were provided with the necessary facilities, all would require a new mobile service tower; in addition, the A4 would require a new launch mount, so these concepts are somewhat more expensive. The three preferred configurations (B3, B4, B6) would each have a total facility cost of approximately $200 million. In terms of total differences between the concepts, there is only a spread of approximately $60 million out of a total program development cost estimated to be $500 to $700 million. Therefore, differences in front-end costs between the final six configurations cannot be considered a key discriminator. Schedule implications associated with facility modifications may have a more significant impact, with those associated with the class A and B2 configurations being the worst.

3.5.7 Summary

A summary of the findings concerning discrimination between the six final configurations is indicated in table 3.5.7-1. No significant differences were found in the areas of SRM design complexity. Class B vehicles with the first-stage SRB's spread apart from the core present a more difficult structural design and analysis task than class A vehicles. All configurations except A3 were acceptable in performance. Class A vehicles were less desirable in stability and control. Facility requirements were more difficult to accommodate with the class A vehicles and B2. Only A4 had a front-end cost that was significantly higher and required additional time.

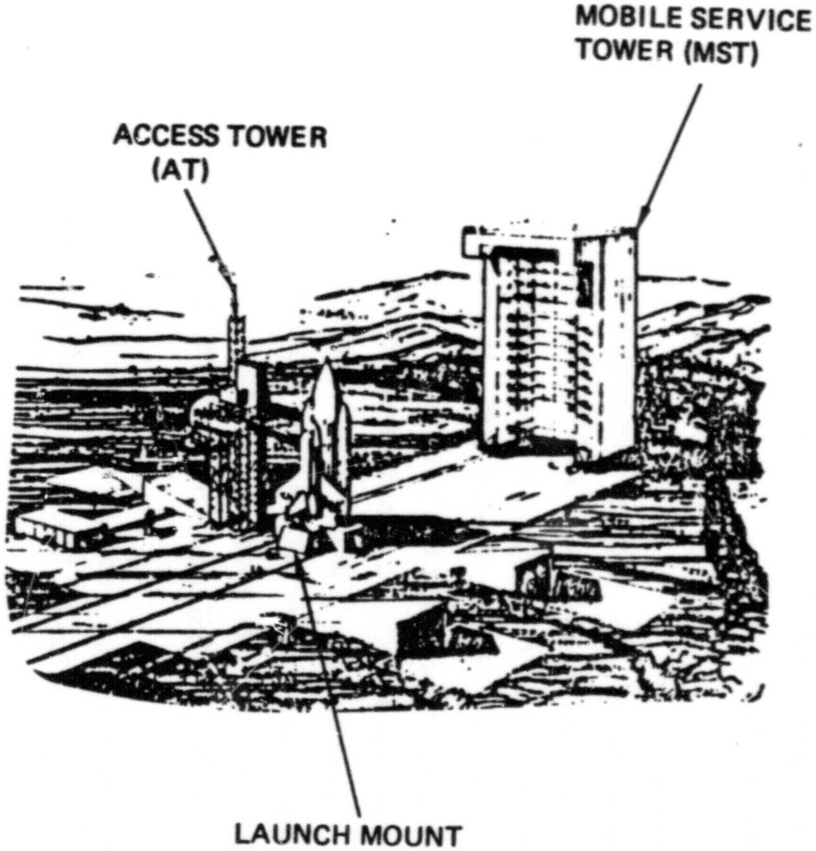
Disposition and rationale assessments are presented in table 3.5.7-2. Three configurations (B3, B4, B6) are indicated for further consideration; a brief description of these follows.

The general arrangement and mass summaries for the B3 and B6 configurations are presented in figure 3.5.7-1. The most significant differences between these configurations is the use of the Titan core stage II for the third stage in B3, while the B6 uses a

Table 3.5.6-4. SLC-6 Impact Assessment—B3, B4, B6

SRB-X-194

EXISTING FACILITIES:



IMPACT AREA	ROM COST (M)

MST
• SRB ACCESS PLATFORMS
• PAYLOAD "WHITE ROOM"
• HYPERGOL SERVICING
  • TITAN 2ND
  • SRB'S
	24.0

LAUNCH MOUNT • CORE SUPPORT PEDESTAL • T–O UMBILICAL	12.0
ACCESS TOWER (AT) • PAYLOAD T–O UMBILICAL • PAYLOAD SERVICES	11.0
LPS	5.0
TOTAL	52.0

NOTE:
1) FOR B-6 SUBTRACT 7.2M
2) NO CENTAUR CAPABILITY
3) PAYLOAD ENCAPSULATION IN MST CLEAN ROOM

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Table 3.5.6-5. SRM and Facilities Cost Discriminators

COST IN MILLIONS (1982 $)

VEHICLE SRM'S [1]	A3 4-2-T2S	A4 T05-4-1-T2	B2 4(2)-4-T2	B3 4(2)-2-T2	B4 3(2)-2-T2S	B6 4(2)-2-S1
STAGE 1 + S/O	1	2	1	1	40	1
STAGE 2	60	45	45	60	60	60
STAGE 3	15	—	—	—	15	30
INTERSTAGE 1/2	—	—	5	5	5	5
SUBTOTAL	76	47	51	66	120	96
FACILITIES [2]						
WTR (SLC-6)	≥ 100 [3]	> 200 [4] [3]	≥100 [3]	52	52	47
ETR	80	78	65	62	62	57
SUBTOTAL	180	278	165	114	114	104
GRAND TOTAL	≥ 256	≥ 325	≥ 226	180	234	200

[1] OTHER ELEMENTS ARE SIMILAR (SHROUD, INTERSTAGES, INST. UNIT, VEH. INTEG & TEST)

[2] DOES NOT INCLUDE SIES, CONTINGENCY, DESIGN

[3] NOT AN OFFICIAL ESTIMATE....A GUESS FOR A NEW MST AND LAND EXCAVATION. CONCEPT MAY NOT BE PRATICAL

[4] REQUIRES NEW LAUNCH MOUNT

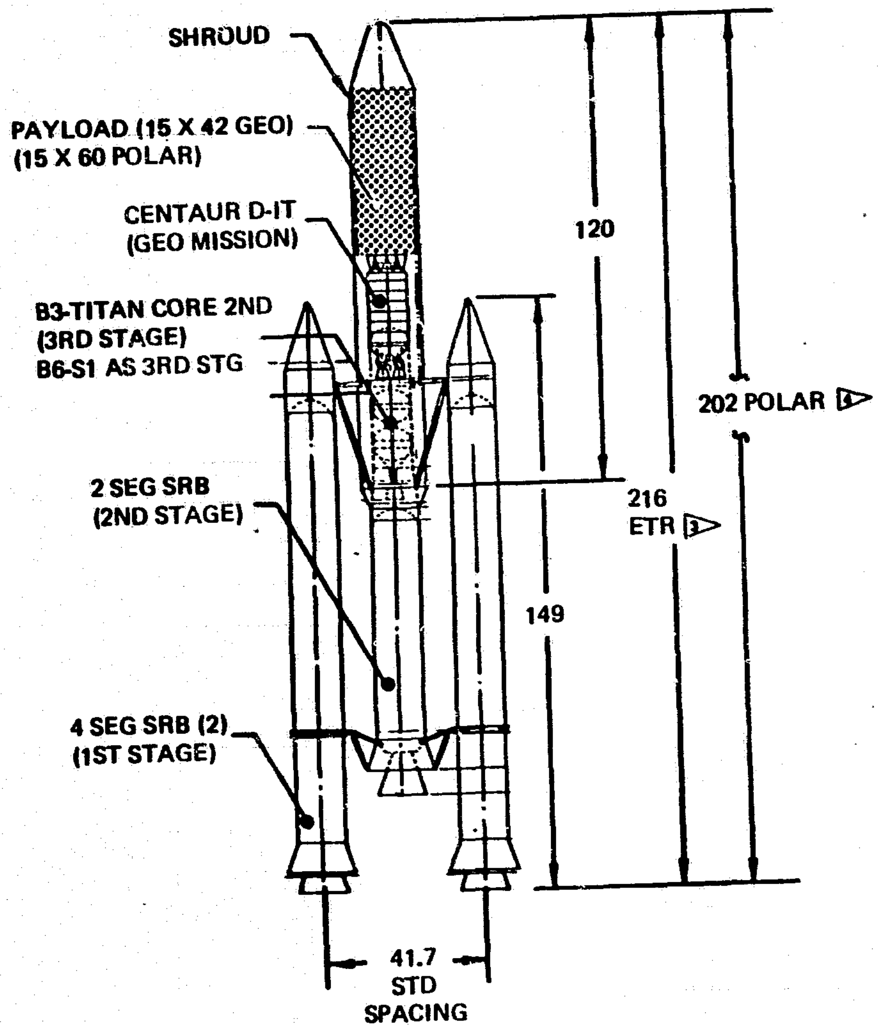
Table 3.5.7-1. *Summary of Key Discriminators*

CONSIDERATION	COMMENT
• SRM DESIGN COMPLEXITY	• ALL REQUIRED MOTORS CAN BE TAILORED FOR ACCEPTABLE TRAJECTORY CHARACTERISTICS
• STRUCTURES	• CLASS B CONFIG. HAVE A MORE DIFFICULT STAGE 1/2 INTERSTAGE
• PERFORMANCE	• A3 MARGINALLY ACCEPTABLE (NEAR TERM) WITH FWC • OTHER OPTIONS SATISFY FAR TERM REQUIREMENTS WITH FWC
• STABILITY/CONTROL	• RIGID BODY DYNAMIC ASSESSMENT AND HISTORICAL FLEX. BODY TRENDS DISCOURAGE USE OF CLASS A VEHICLES • B3 AND B6 PROVIDE GREATER MARGINS THAN B4
• FACILITY MODIFICATIONS (DIFFICULTY & SCHEDULE)	• B3, B4, B6 MINIMUM AT BOTH ETR & WTR • B2 MINIMUM AND A3 MODERATE AT ETR BUT EXTREME AT WTR • A4 MODERATE AT ETR BUT VERY EXTREME AT WTR
• DEVELOPMENT COST (FACILITY AND SRM'S)	• TOTAL INDICATES NO SIGNIFICANT DIFFERENCES EXCEPT FOR A4

Table 3.5.7-2. Configuration and Concept Assessment

CONFIGURATION [1]		DISPOSITION	COMMENT
A3	4-2-T2S	DROP	STABILITY CONCERNS, FACILITY SCHEDULE AND MARGINAL PERFORM.
A4	T05-4-1-T2	DROP	NOT PRATICAL AT WTR W/O NEW LAUNCH MOUNT, MST ETC
B2	4(2)-4-T2	DROP	OTHER CONCEPTS HAVE COMPARABLE PERFORM. WITH LESS GLOW AND FACILITY IMPACT
B3	4(2)-2-T2	RETAIN	USE AS REFERENCE SYSTEM
B4	3(2)-2-T2S	RETAIN	PROVIDES 1ST STAGE ALTERNATIVE
B5	4(2)-2-S1	RETAIN	PROVIDES 3RD STAGE ALTERNATIVE. COULD ALSO BE USED WITH B4 INSTEAD OF T2S.

[1] D-IT CENTAUR ADDED TO ALL CONFIGURATIONS FOR GEO MISSIONS



ALL DIMENSIONS IN FEET

MASS SUMMARY (K LBS) GEO MISSION

	B3	B6
STAGE 1 [1]	2580	2580
1/2 INTERSTAGE	15	15
STAGE 2 [1]	702	702
2/3 INTERSTAGE	2	2
STAGE 3 [1]	75	108
3/4 INTERSTAGE	1	1
STAGE 4 [1]	34.5	34.5
4/PAYLOAD ADAPTER	0.5	0.5
SHROUD	15.3	15.3
PAYLOAD [2] - GEO	11.7	11.5
GLOW =	3437	3470
OTHER PAYLOADS		
POLAR (SUN SYNC)	34	34
LEO	42	44

[1] STEEL CASES

[2] WITH FWC ADD 6K LEO, 6K POLAR AND 1K GEO

[3] NEW 50t CRANE DESIGN WOULD ACCOMMODATE 230 FT

[4] 192 FT WITH 50 FT PAYLOAD

Figure 3.5.7-1. Configurations B3 and B6

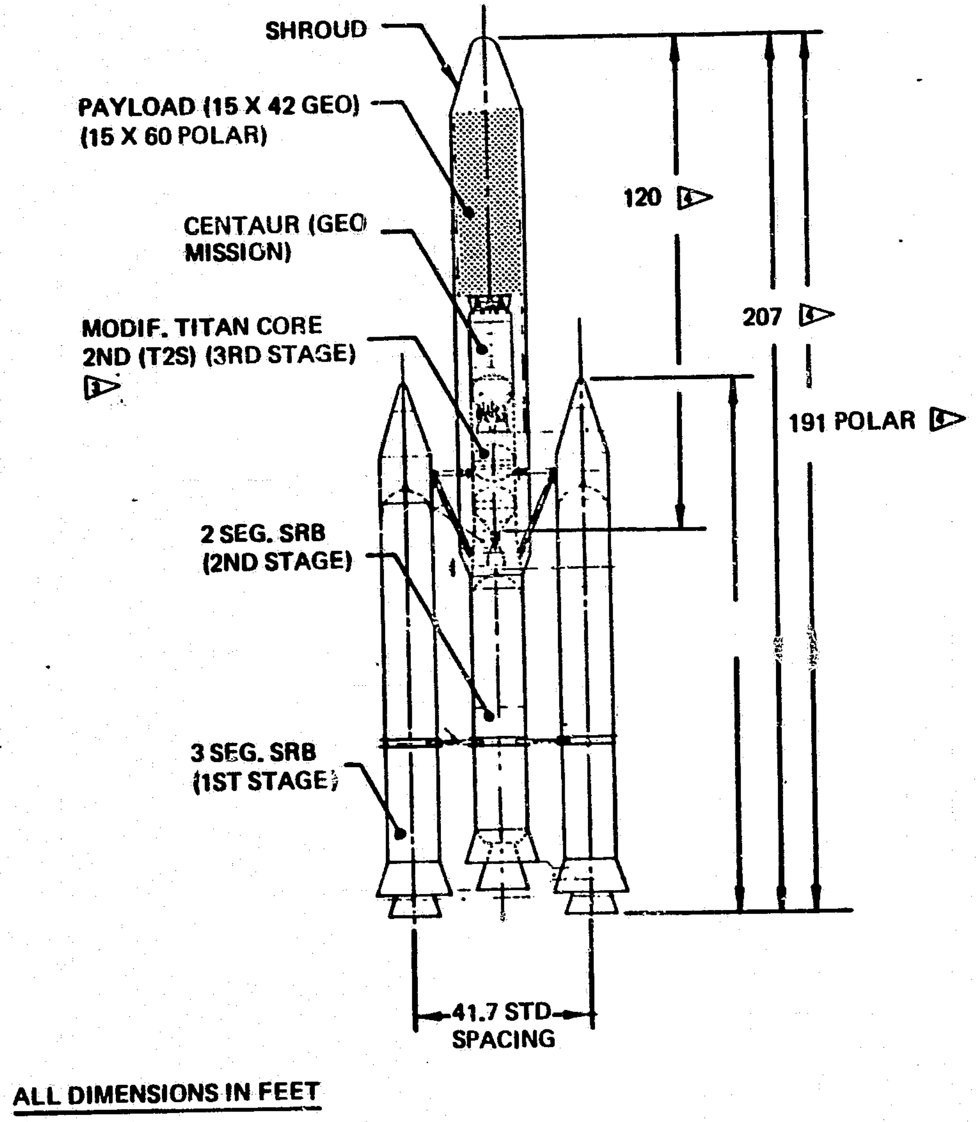
modified version of the MX first stage (S1) for its third stage. The overall height of the two configurations is essentially the same because the Titan core stage II and S1 have nearly the same length. Spacing of the first-stage SRB's is identical with that of the STS. The height (216 ft) of the GEO mission configuration can be accommodated with the 50t boom crane that is used for payload changeout at the pad. A height reduction of approximately 8 ft is necessary on the polar configuration to make it compatible with WTR facility constraints (MST). The GLOW for these vehicles is a little over 3,400,000 lb. Payload capabilities for LEO, Sun synchronous and GEO are, respectively, 42,000, 34,000 and 11,700 lb when using steel case SRM's. Use of FWC's would add 6000 lb for the LEO type missions and 1000 lb for a GEO mission.

The B4 configuration and characteristics are shown in figure 3.5.7-2. The first-stage SRB's of this concept are made up of three rather than four segments, as in B3 and B6. This configuration also requires use of a stretch Titan core stage II (an additional 41,000 lb of propellant—delta L = 7 ft) in order to achieve payloads of the same magnitude as B3 and B6. The GLOW for the B4, however, is approximately 600,000 lb less. The result of the shorter first stage is that it allows the core (second, third, fourth stages and payload) to be lower and, thus, it has a total height that can be accommodated at WTR without any vehicle height reduction. The 50t crane is still required at ETR, however, for payload changeout.

3.5.8 Recommended Concept

As indicated from the foregoing descriptions, three configurations had similar characteristics for the system elements employed. The recommended concept, however, is the B3, based on the following rationale. Although the B4 had similar performance, it was helped considerably by use of a stretch T2 (T2S) rather than standard T2. Should the T2S be used with the B3, its performance should be somewhat better than B4. The B6 also had comparable payload as the B3, but the S1 used for the third stage has nearly reached its limit in terms of performance. Again, the B3 could employ a stretch version of the T2 as well as an improved nozzle, offering considerable improvement.

Consequently, the B3 concept was judged to offer the best overall characteristics and was used to obtain a more complete definition as the SRB-X configuration in section 4.0.



MASS SUMMARY (K LBS) GEO MISSION

	WITH T2S
STAGE 1 ▷1	1974
1/2 INTERSTAGE	13
STAGE 2 ▷1	702
2/3 INTERSTAGE	2
STAGE 3 ▷1	117
3/4 INTERSTAGE	1
STAGE 4 ▷1	34.5
4/PAYLOAD ADAPTER	0.5
SHROUD	16
PAYLOAD ▷2	11.4
GLOW =	2871.4
OTHER PAYLOADS	
POLAR (SUN SYNC.)	34
LEO	44

▷1 STEEL CASES
▷2 WITH FWC ADD 50K LEO, 5K POLAR AND 1K GEO
▷3 S 1 WILL ALSO BE CONSIDERED
▷4 ADD 7 FEET WHEN USING T2S

Figure 3.5.7–2. Configuration B4

4.0 CONCEPT DEVELOPMENT

This section provides further analysis of the basic concept in terms of alternatives to improve vehicle performance and additional subsystem definition that will provide characteristics for the final configuration.

4.1 PERFORMANCE IMPROVEMENT OPTIONS

The basic concept resulting from the screening analysis consisted of a first stage with two standard STS four-segment steel case SRB's, a nonoptimized two-segment steel case SRB for the second stage, and a standard Titan core stage II serving as the third stage.

Although the GEO payload capability of the selected vehicle was considerable at 11,700 lb, there appeared to be an increasing need to satisfy a 15,000-lb requirement expected during the 1990's. As a result, potential improvements were identified and are indicated in figure 4.1-1. Key features of these improvements, relative to the basic vehicle, are summarized below.

a. Stage 1—Basic: two STS four-segment SRB's with steel case SRM's. Improvements: (1) filament wound case to reduce inert weight and (2) higher operating pressure for increased thrust and reduced gravity losses—same basic case but safety factor for unmanned vehicle (1.25 versus 1.4) allows a higher maximum expected operating pressure (MEOP).

b. Stage 2—Basic: two-segment SRB with steel case SRM. Improvements: (1) filament wound case for reduced inert weight, (2) higher operating pressure for higher thrust and less gravity loss, and (3) optimized expansion ratio for improved specific impulse.

c. Stage 3—Basic: standard Titan core stage II. Improvements: (1) increased propellant load by 50% and (2) expansion ratio changed from 49 to 66 for 3-sec improvement in specific impulse.

d. Stage 4—Basic: standard Centaur D-IT. Improvement: advanced cryogenic stage such as HEUS, with more propellant and better mass fraction.

4.2 SUBSYSTEM ANALYSIS

The analysis was focused to support the investigation of the performance improvement options as well as to provide a more complete definition of the vehicle. Those areas analyzed included propulsion systems, new structural elements, avionics for vehicle control, and additional stability and control analysis.

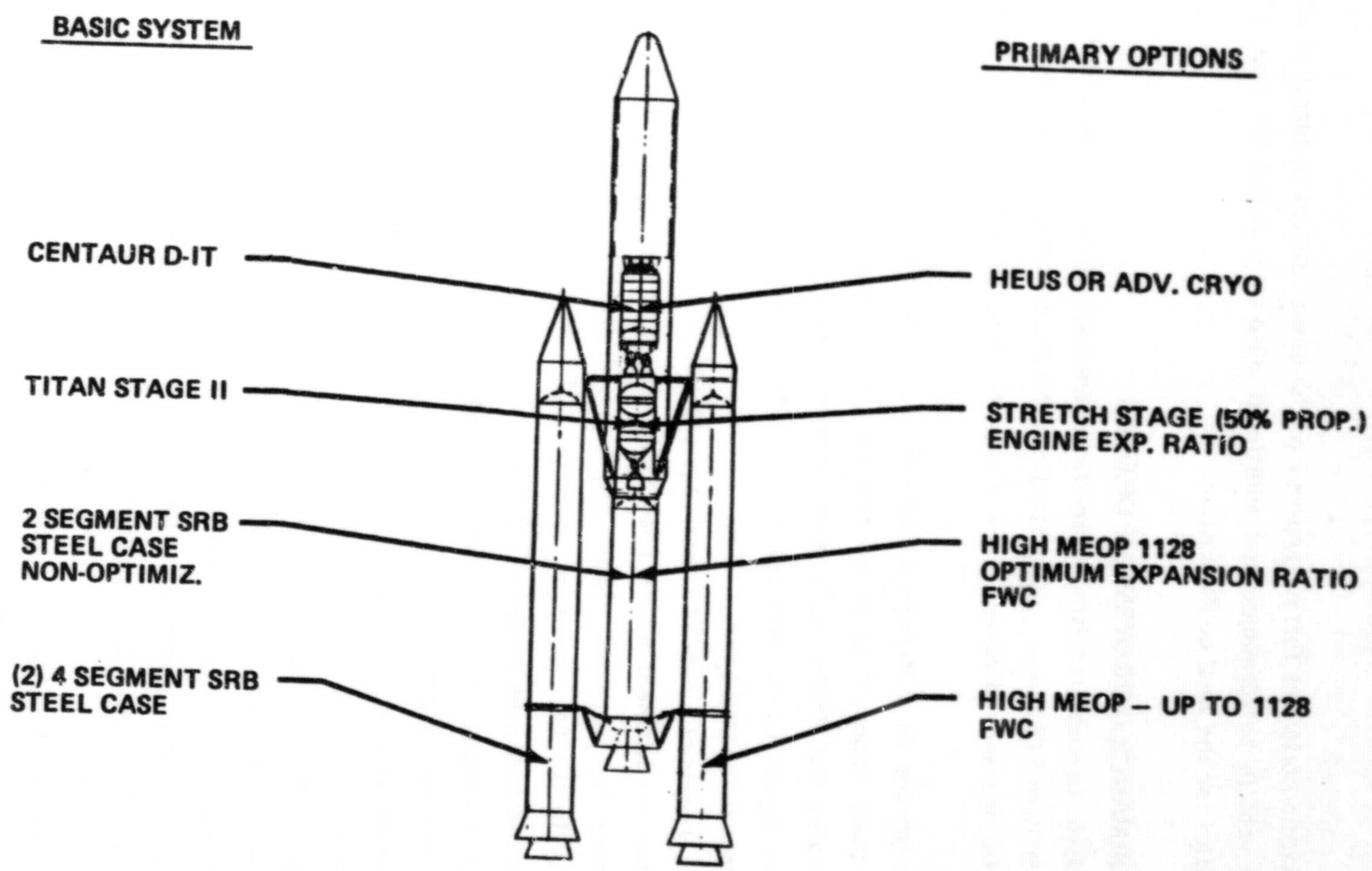


Figure 4.1-1. Configuration Performance Improvement Options

4.2.1 Propulsion Systems

The propulsion analysis at this point was focused primarily on further definition of the SRM's, although some effort was devoted to the liquid third and fourth stages.

4.2.1.1 SRM Definition

Further definition was performed on a four-segment and a two-segment SRM. The design constraints used in the analysis were as follows:

a. Maximum thrust to weight: 3.6g's.

b. MEOP consistent with design factor of safety of 1.25.

c. Maximize use of current SRM hardware and propellant formulation.

d. Maintain size and weight to conform with existing processing and launch facilities.

e. Configurations to allow substitution of filament wound case (FWC) components.

f. Configurations satisfy stage-to-stage interfaces for SRB-X.

Four-Segment High-MEOP SRM. The high-MEOP SRM was used to investigate a higher thrust first stage that could reduce gravity losses and thus improve payload capability. An unmanned vehicle generally allows a 1.25 safety factor rather than 1.4 for manned and thus provides the opportunity to increase the MEOP from 1007 psia to 1128 psia. The higher MEOP corresponds to the proof pressure used in the basic STS SRM and therefore does not present a completely new environment.

To achieve the higher pressure an increase in burn rate would also be necessary, but this increase must remain within the limits of the standard propellant, TP-H1148.

The resultant motor performance and thrust history are summarized in table 4.2.1-1 and figure 4.2.1-1, respectively, and are compared with a standard HPM. A maximum thrust of 4,050,000 lbf and an Isp of 267.8 sec are provided by the high-MEOP SRM versus the HPM characteristics of 3,175,000 lbf and Isp of 267.2 sec. Notice the burn rate increase from 0.42 to 0.48 ips at 1000 psia and the attendant decrease in burn time. All other components are standard HPM hardware.

Two-Segment SRM. The stage 2 SRM resulting from the concept and configuration trades (sec. 3.0) consisted of a basic two-segment SRM that had not been optimized. Areas for optimization included the thrust profile to minimize g losses and expansion ratio for higher Isp, as well as reexamination of the propellant loading and utilization of the 1.25 safety factor that allows a higher MEOP. In addition to those indicated previously, the primary design consideration was continued use of the STS SRM propellant; however, a new grain design was acceptable.

Table 4.2.1-1. *High-MEOP Four-Segment SRM Performance Summary*

	High Thrust SRB-X	Standard HPM
Burn Time (sec.)	105.5	124.5
R_{BO} (1,000 psia) (ips)	0.48	0.42
Ispv (lbf-sec/lbm)	268.37	268.0
Total Impulse (lbf-sec)	297.246×10^6	296.978×10^6
Initial Expansion Ratio	7.72	7.72
Average Expansion Ratio	7.42	7.42
Initial Throat Diameter (in.)	53.86	53.86
Average Chamber Pressure (psia)	709	601
MEOP (psia)	1,128	1,007
Propellant Wt. (lbm)	1,107,590	1,107,590
SRM Inert Wt. (lbm)	146,127	146,127

Thiokol/WASATCH DIVISION

Thiokol/WASATCH DIVISION

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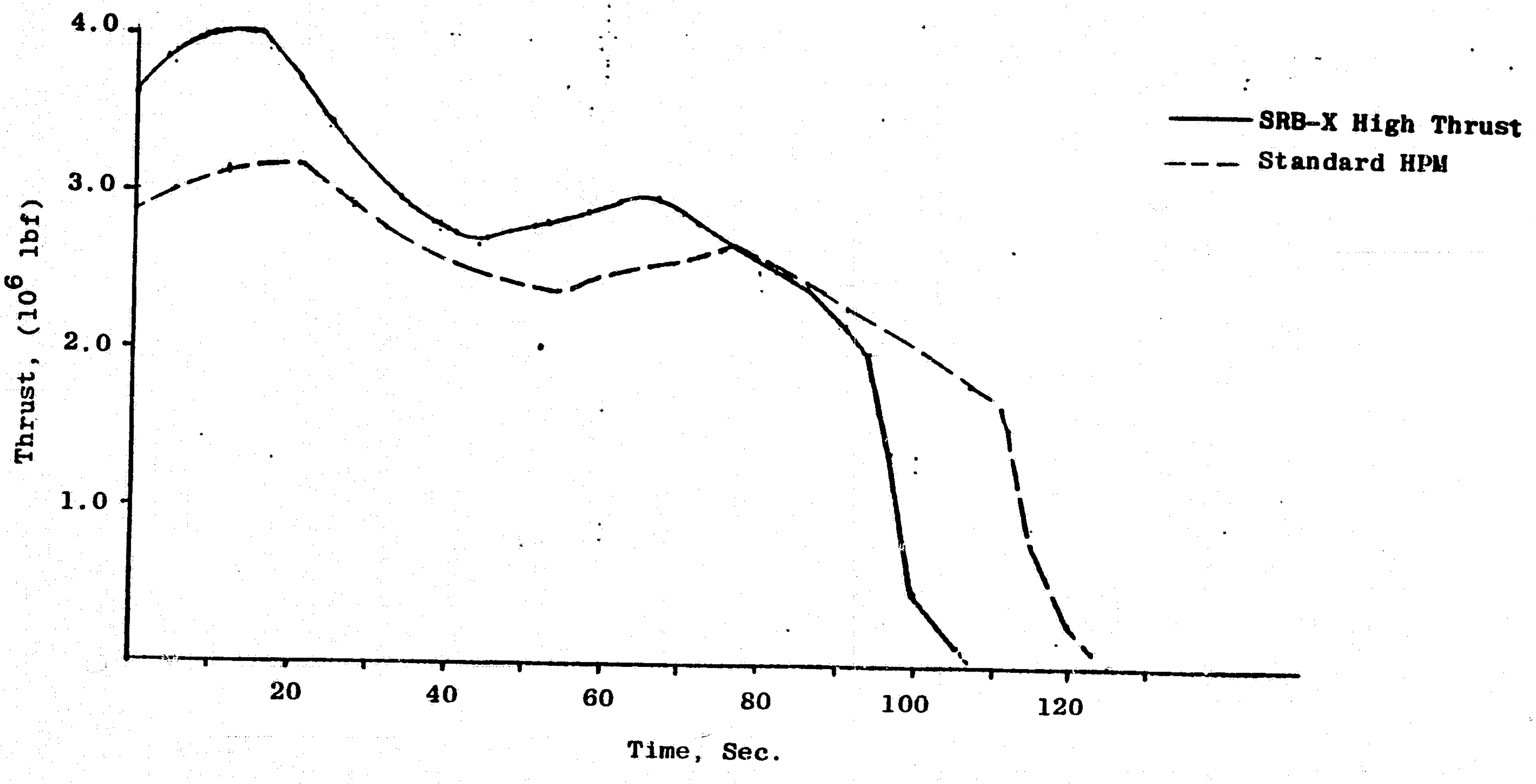


Figure 4.2.1-1. Thrust-Time History

B10.

Optimization Options. The variations of this motor characterized to assess sensitivity of thrust level, Isp, and inert weight in terms of vehicle payload capability are summarized in table 4.2.1-2. Ballistics data for each motor also were developed. Configuration 1 is the SRM resulting from section 3.0. A similar SRM but with higher expansion ratio is indicated by 1a. Motor configurations 2, 3, and 4 were defined to show the impact on Isp and nozzle weight when a constant g level was provided. Configuration 5 relates to a motor that attempts to obtain the highest possible Isp, but with a variable thrust profile that includes a lower maximum value and, thus, less nozzle weight. Configuration 6 is similar to 5 except consideration was given to manufacturing limitations (wrapping and autoclave). As a result, the largest nozzle exit diameter which appears possible is 166 in.

Comparison of Options. An overview of the options and comparison of several propellant loadings are presented in figure 4.2.1-2. The indicated conditions for performing the propellant loading trades are typical of the parameters investigated. As indicated, the two-segment loaded results in a small payload loss. The advantage, versus the other loadings, however, is that it is easily adaptable to filament wound cases whereas a 2-1/2 segment is not. Compared with a three-segment SRM, it requires less thrust and tailoring to satisfy g constraints.

The influence of g level (thrust profile), expansion ratio (Isp), and MEOP in terms of vehicle LEO capability is shown in figure 4.2.1-3. All options are keyed to the reference system from section 3.0. The three constant g cases (options 2, 3, and 4) indicate that a benefit occurs with lower g because a lower thrust is necessary, which allows a higher expansion ratio (more Isp) and less inert weight. Option 5 provides the maximum capability for the options investigated by a variable g profile with a relatively low initial g that again allows a more optimum nozzle. Unfortunately, the 197-in-diameter nozzle was found to be too large for the known manufacturing capabilities. The selected SRM, therefore, had the variable g profile but with the nozzle diameter restricted to 166 in (the STS HPM is 149). As such, the selected design provided a 2000-lb payload gain over the reference design.

Final Design Features. The final definition of the two-segment SRM occurred as a result of interaction with the vehicle configuration design activity. As a result, it was determined that a more desirable structural interface would occur between first and second-stages if the second-stage SRM consisted of forward and aft segments from the STS SRM rather than forward and center segments. With this design, the ET attachment section of the aft segment can be used to connect the aft struts coming from the stage 1 SRB's. Accordingly, the propellant and inert weight were adjusted.

Table 4.2.1-2. Two-Segment SRM Optimization Options

CONFIGURATION	ϵ_{IN}	ISP	R_b IN/SEC	TBURN SEC	NOZZLE * WT LBM	REMARKS
1 REFERENCE	17.9	285.12	0.28	186	13,168	MEOP-1016 NOZZLE DIA = 132.0 IN NOZZLE FS = 1.25
1A REFERENCE	40.0	295.3	0.28	186	17,800	MEOP-1016 NOZZLE DIA = 196.5
2 3.6G CONSTANT	18.3	285.87	0.54	100	18,128	MEOP-1128 D_E = 196.5
3 3.0G CONSTANT	22.3	288.88	0.44	124	17,591	MEOP-1128 D_E = 196.5
4 2.4G CONSTANT	28.4	292.33	0.36	153	17,045	MEOP-1128 D_E = 196.5
5 VARIABLE G	39.5	296.27	0.32	151	16,096	MEOP-1128 D_E = 196.5 MAX G = 3.6
6 VARIABLE G	27.2	291.57	0.32	151	14,459	MEOP-1128 D_E = 166 MAX G = 3.6

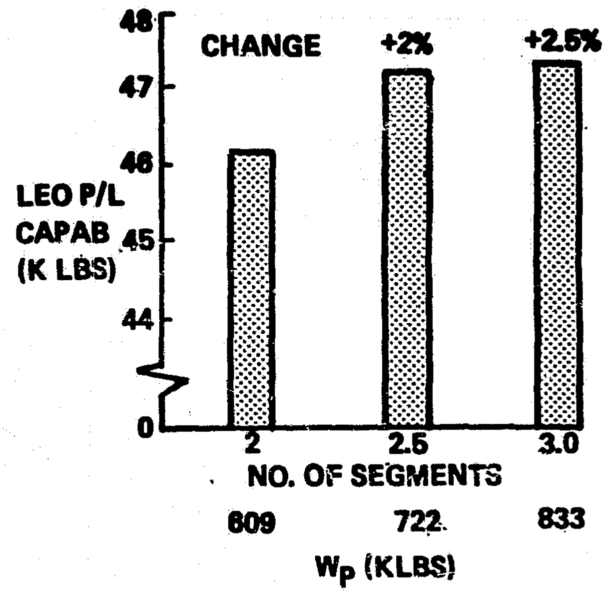
* A WEIGHT INCREASE MAY BE ADDED TO THE STAGE INERT WEIGHTS TO ACCOUNT FOR TVA SIZING AS THE MOVABLE NOZZLE INERTIA INCREASES

PARAMETERS	1ST QUARTER REFERENCE	OPTIONS
• PROP. LOAD (NO. OF SEGMENTS)	2	2, 2.5, 3
• G LEVEL (VEHICLE)	VARIABLE 1.5/2.8 [1]	VARIABLE MAX = 3.6 CONSTANT 3.6, 3.0, 2.4
• EXP. RATIO	17.6	UP TO 40
• MEOP (PSIA)	1016	1128

[1] INITIAL/FINAL

PROPELLANT LOADING SELECTION

- CONST G = 3.0
- MEOP = 1016
- EXP RATIO = 40
- CONST MASS FRACTION = .882
- STD STG 1 AND 3

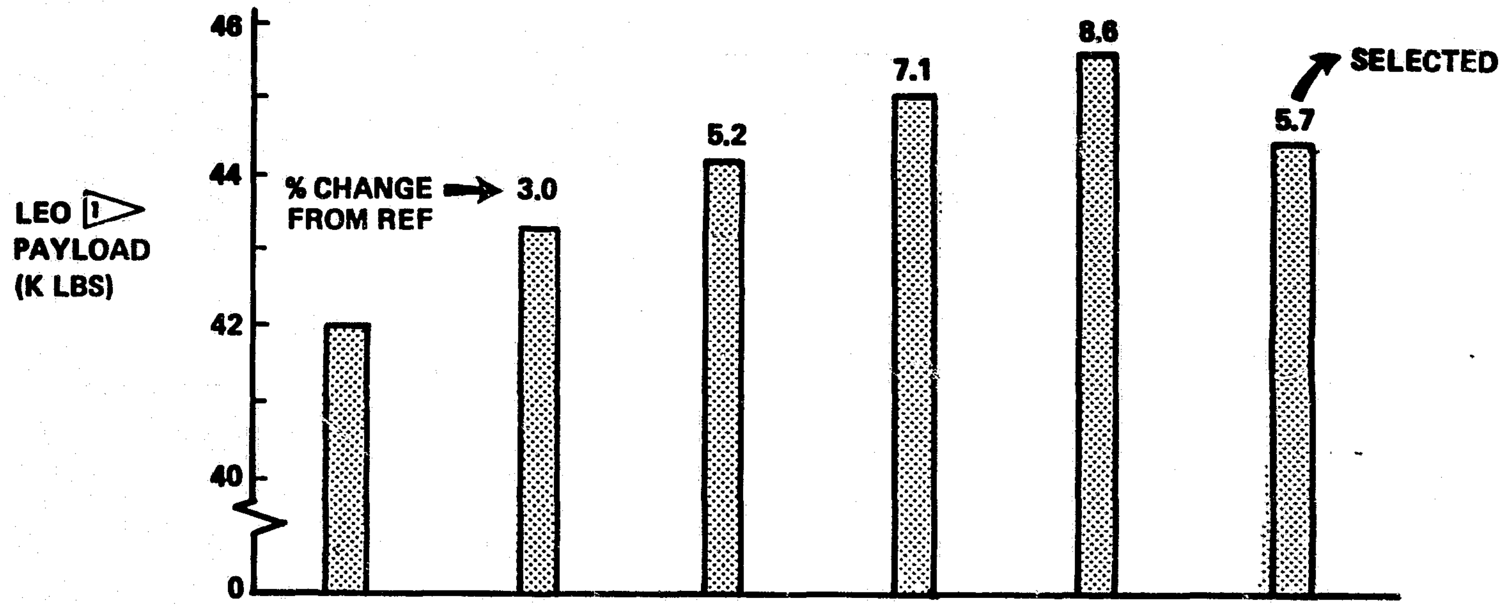


SELECT 2 SEGMENTS

SMALL PAYLOAD LOSS
BUT
REQUIRES LESS THRUST & TAILORING
MORE ADAPTABLE WITH FWC

Figure 4.2.1-2. Stage 2 Performance Trades

[1] STG 1 (2) STD STS SRB'S
STG 2 HAS 2 SEG
STG 3 TITAN CORE STG II



DESIGN OPTION	REF. 1ST QTR	1	2	3	4	5
G LEVEL [2] INITIAL/FINAL	VAR. [2] 1.5/2.3	CONST 3.6	CONST 3.0	CONST 2.4	VAR. 1.7/3.6	VAR. 1.7/3.6
EXIT DIA. (IN.)	132	197	197	197	197	166 [3] CURRENT MFG LIMIT
EXP. RATIO	17.9	18.3	22.3	28.4	39.5	27.2
I_{SP} (SEC)	285.1	285.9	288.9	292.3	296.3	291.6
NOZZLE WT (K LBS)	13.2	18.1	17.6	17.0	16.1	14.5
MEOP (PSIA)	1016	1128	1128	1128	1128	1128

Figure 4.2.1-3. Stage 2 Performance Comparison

The basic motor layout is shown in figure 4.2.1-4. All aft segment components are standard, but the stacking order is changed. The two stiffener segments are at the forward end and the ET attach segment is last, allowing alignment of the 1-2 interstage structure. The grain design is new but designed for minimum tooling costs. The forward segment web is 44 in (same as STS), but the 11 fins are repositioned at the aft of the casting segment. Since the fins are shorter than the standard HPM, this change permits cheaper noncollapsing fin core tooling. The grain design objective was to match, as closely as possible, the idealized optimized trace from the ADFO model. A comparison between ideal and designed thrust traces in figure 4.2.1-5 shows a good match. Performance data are summarized in table 4.2.1-3 for both actual grain design and idealized optimums. Although the 157-sec burn time is longer than standard STS motors, a reduction in insulation safety factors is expected to reduce the case internal insulation requirement. This results from the decreased safety factor for a non-man-rated system and from considering that the second stage is too high and fast at burnout to recover for reuse.

4.2.1.2 Liquid Systems

Stage 3 Revisions. Interaction with the configuration activity also resulted in a revision of the stretch Titan stage II being used as the third stage for SRB-X. In this case, limitations on the vehicle height, when launched at VAFB, required a 1-ft reduction in the length relative to that used for the third screening. The final performance characteristics assumed for the stage are as follows:

a. Propellant: 101,380 lb.

b. Inerts: 9455 lb.

c. Isp: 319 sec.

Stage 4 Revisions. Midway through the study, considerable effort was put forth by both NASA and the Air Force on an advanced cryogenic upper stage designated as HEUS. HEUS was to provide the capability to deliver approximately 16,000 lb to GEO when launched from the shuttle. Because SRB-X was to be capable of launching shuttle payloads, the launching of HEUS and its payload was an assumed requirement. Primary performance characteristics assumed for HEUS are as follows:

a. Propellant: 38,000 lb.

b. Inerts: 6000 lb.

c. Isp: 445 sec at mixture ratio of 5.5:1.

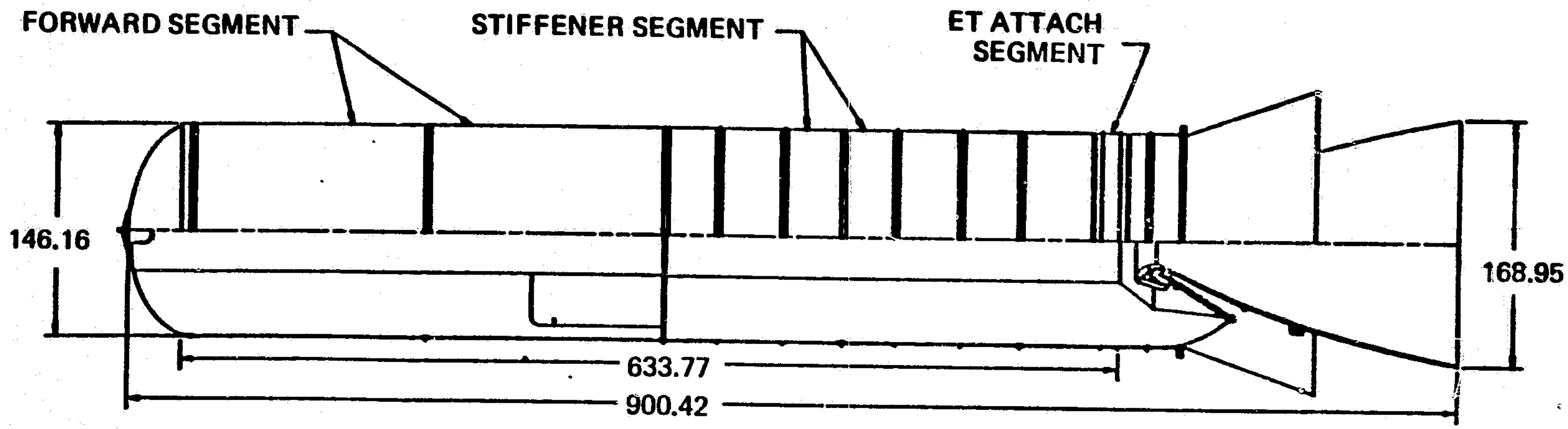


Figure 4.2.1-4. Two-Segment Second-Stage SRB-X Motor

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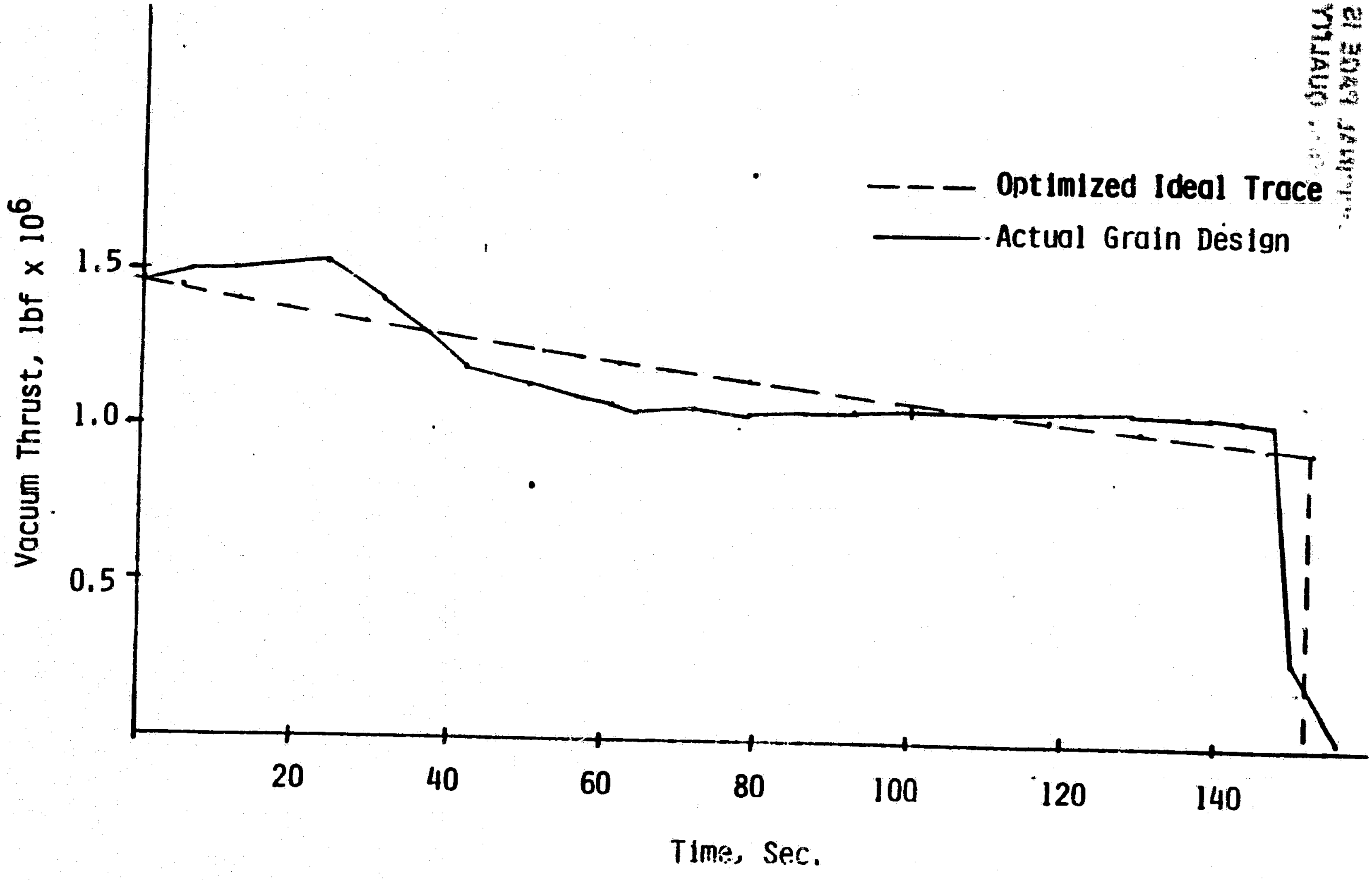

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Figure 4.2.1-5. Ideal Versus Designed Thrust Trace Comparison

Table 4.2.1-3. Two-Segment Second-Stage SRM Performance Summary

	Actual Grain Design	Idealized Optimum
Burn Time, sec.	156.6	152
R_{BO} (1,000 psia), ips	0.3198	0.3198
Ispv, lbf-sec/lbm	292.86	292.92
Total Impulse, lbf-sec x 10^6	177.05	180.12
Initial Expansion Ratio	27.75	27.91
Average Expansion Ratio	24.85	24.93
Initial Throat Diameter, in.	31.51	31.42
Average Chamber Pressure, psia	707	743
MEOP, psia	1,128	1,128
Average Vacuum Thrust, lbf x 10^6	1.130	1.18
Propellant Weight, lbm	605,136	614,900
Inert Weight, lbm (LWC)	83,307	83,273

4.2.2 Structural Analysis

This section provides a preliminary structures definition of the basic B3 vehicle in the following areas: interstage 1-2 struts, payload shroud, stage 2 forward skirt, and assessment of stage 1 and 2 SRM stiffness. The payload shroud analyzed was made up of three sections: the payload/Centaur D-IT section, the ring section (reacts loads from forward lateral struts), and the section surrounding the third stage (T2 section). The final structural definition in section 5.0 had the ring section and T2 section combined with the forward strut system to form the stage 1-2 forward interstage structure.

4.2.2.1 Interstage 1-2 Struts

Design Concept and Approach. The structural concept of the interstage 1-2 struts is shown in figure 4.2.2-1. The approach used in designing the struts is summarized in table 4.2.2-1. Major emphasis was placed on the interplay between strength requirements and stiffness requirements with regard to defining the strut basic tube sections. A conservative but practical engineering approach was used to define strut end fitting and separation bolts.

Design Considerations. The considerations used in designing the struts were the axial loading condition and stiffness characteristics. The axial load impact on the drag strut at liftoff is shown in table 4.2.2-2. A dynamic magnification factor was developed from the STS data base and applied to the SRB-X baseline vehicle. The result is an estimated axial load transfer between stage 1 SRB and core vehicle (stages 2, 3, 4 and payload) of 1513 kips. The comparable STS load between SRB and ET is 1363 kips. (The maximum STS load occurs at SRB max g and is 1672 kips.)

The axial load transfer via the drag strut during stage 1 flight is presented in figure 4.2.2-2. As indicated, the load ranges from a minimum of 661 kips at liftoff steady-state onset to a maximum of 1240 kips at stage 1 max g. Note that this inflight maximum load is considerably less than the liftoff transient load of 1513 kips.

Assessment of the drag struts for stiffness verification is presented in figure 4.2.2-3. This assessment involved sizing the drag struts for strength and incorporating their characteristics into a simplified dynamics model. The first flexible body mode resulting from the dynamics analysis is an asymmetrical longitudinal translation of stage 1 SRB's. As such, the mode is a primary indicator of the dynamic response of the drag struts. The mode frequency is 2.3 Hz. (It is a design goal that lower mode frequencies be greater than 2 Hz in order to provide at least four times the flight control system

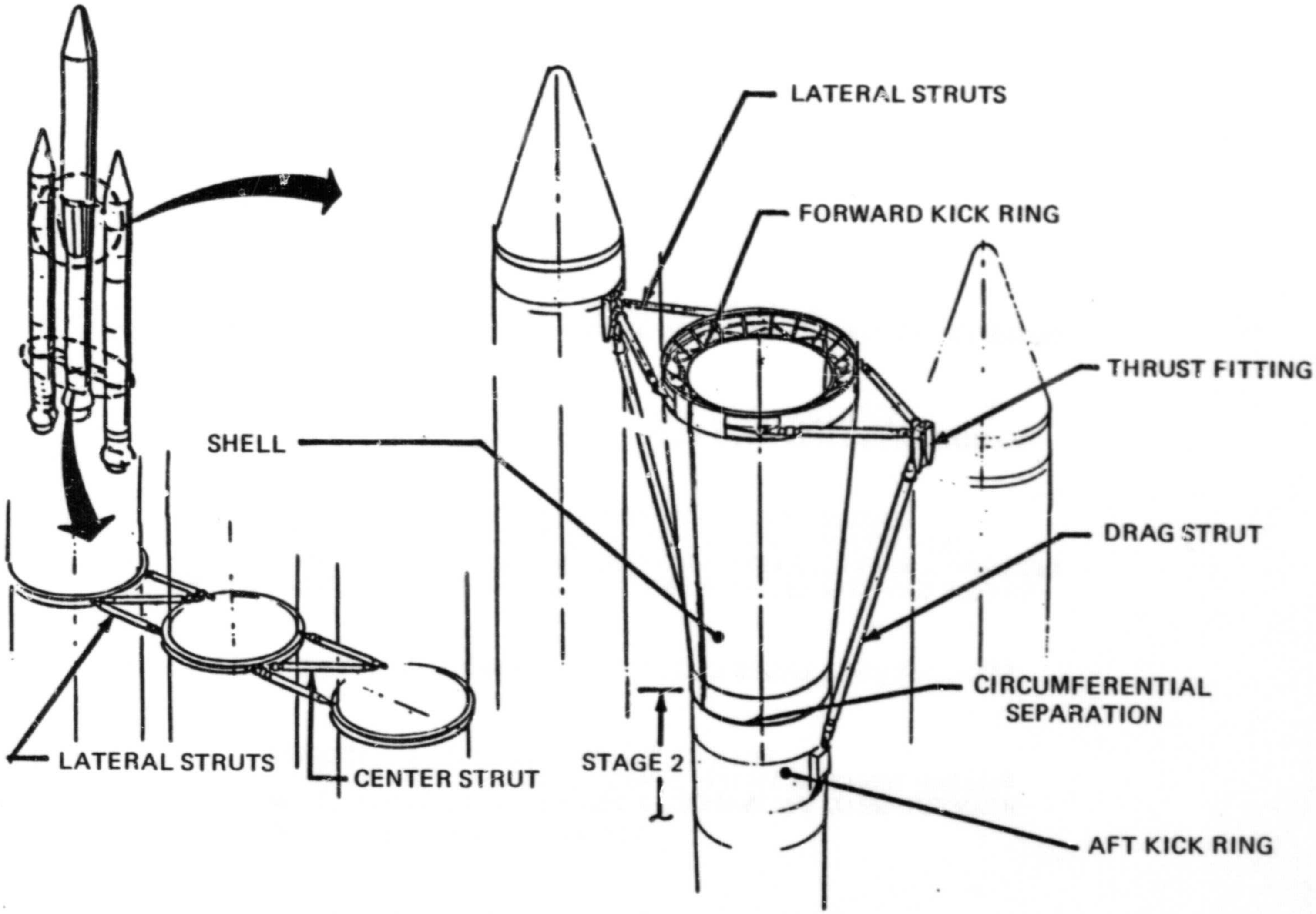


Figure 4.2.2-1. Interstage 1-2 Struts

Table 4.2.2-1. Strut Design Approach

- DEFINE LOAD REQUIREMENTS
  - LIFTOFF TRANSIENT CONDITION
  - MAX $q\alpha$ (5000 PSF-DEG SELECTED FOR STRUCTURAL DESIGN)
  - MAX g (2.82 MAX DURING STAGE 1 OPERATION)
- DEFINE STIFFNESS REQUIREMENTS
  - WANT VEHICLE LOWER MODE FREQUENCIES TO BE GREATER THAN 2 HZ (i.e., AT LEAST 4 TIMES FLIGHT CONTROL SYSTEM FREQUENCY OF APPROXIMATELY 0.5 HZ)
- USE HIGH STRENGTH STEEL (220 KSI) FOR STRUT TUBE SECTIONS
- FOR STIFFNESS CRITICAL STRUTS, USE END FITTINGS AND SEPARATION BOLTS WITH A TENSION LOAD CAPABILITY NO LESS THAN THAT OF THE TUBE SECTIONS (i.e., CONSERVATIVE APPROACH WHICH MAXIMIZES STRUT STRENGTH CAPABILITY AND WEIGHT)
- USE THE STS SRB/ET STRUTS AS A DATA BASE FOR DEFINITION OF STRUT COMPONENTS OTHER THAN THE TUBE SECTIONS
- TO THE MAXIMUM EXTENT PRACTICAL (WEIGHT/COST), USE COMMONALITY OF END FITTINGS AND SEPARATION BOLTS.

Table 4.2.2-2. *Axial Load Transfer Via Drag Strut at Liftoff*

STS DATA BASE

AT LIFTOFF (VEHICLE T/W = 1.00):

T_{SRBx1} = 1,682,500 LBF

W_{SRBx1} = 1,294,000 LB

DURING LIFTOFF TRANSIENT:

$P_{X_{MAX}}$ = 1,363,000 LBF

DYNAMIC MAGNIFICATION FACTOR REFERENCED TO LIFTOFF CONDITION $= \dfrac{1{,}363{,}000}{(1{,}682{,}500-1{,}294{,}000)} = 3.51$

SRB-X APPLICATION

AT LIFTOFF (VEHICLE T/W = 1.00):

T_{SRBx1} = 1,722,000 LBF

W_{SRBx1} = 1,291,000 LB

DURING LIFTOFF TRANSIENT:

$P_{X_{MAX}}$ = 3.51 (1,722,000–1,291,000) = 1,513,000 LBF [1]

[1] APPROX 90% OF STS LIMIT DESIGN LOAD OF 1,672,000 LBF (MAX g CONDITION)

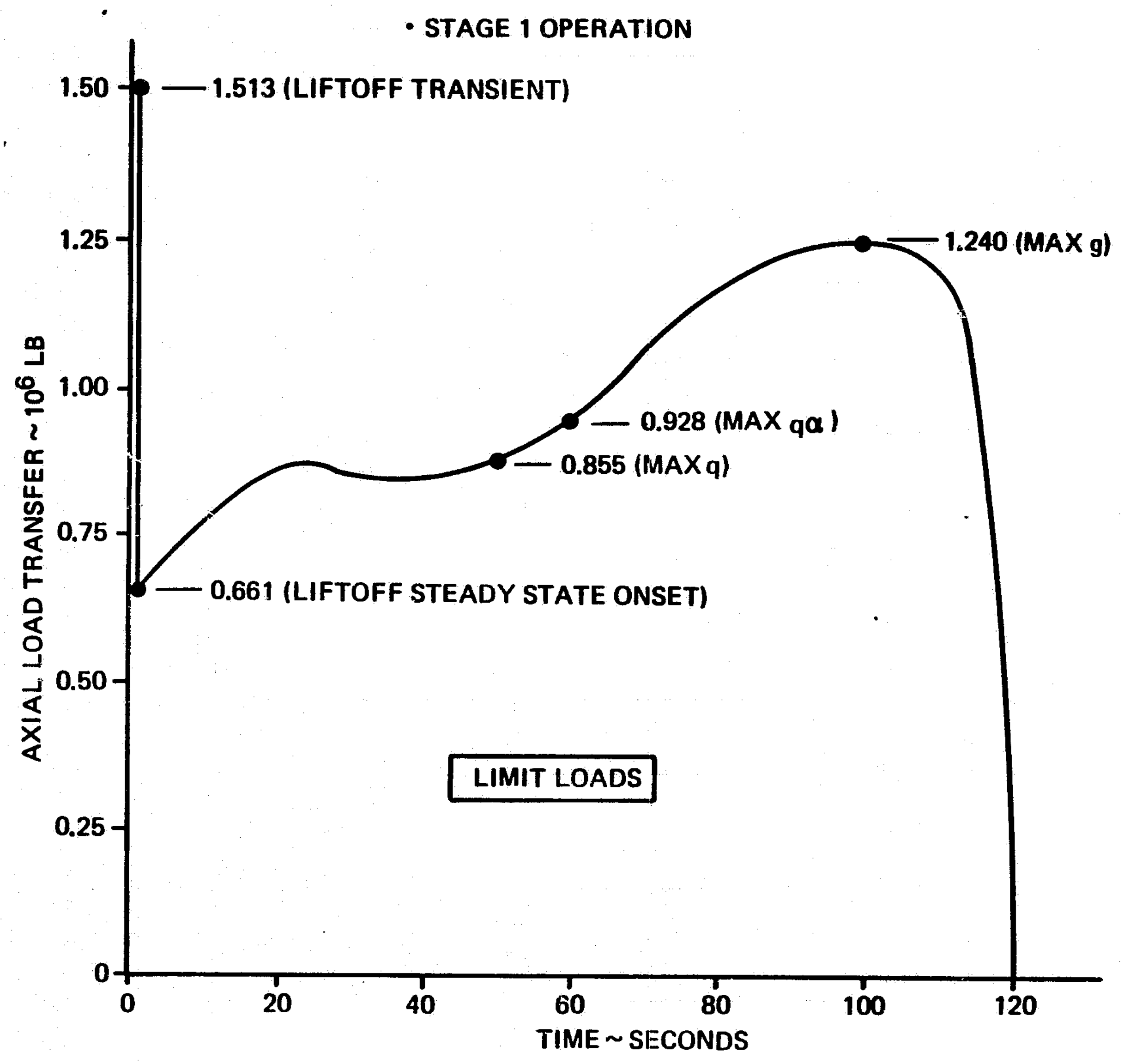
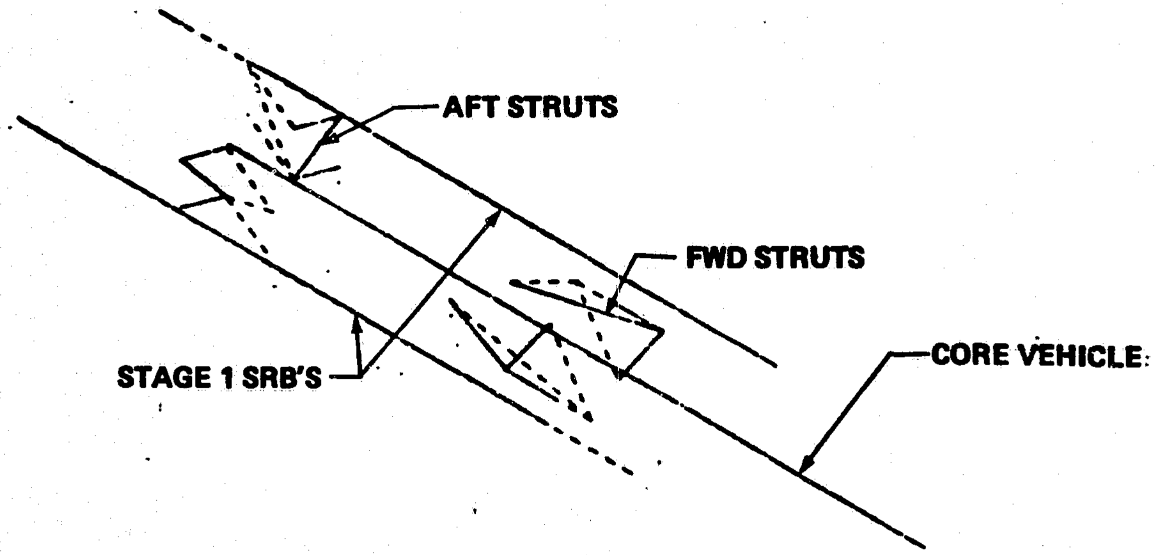


Figure 4.2.2-2. Axial Load Transfer Via Drag Strut During Flight

- FIRST FLEXIBLE BODY MODE IS ASYMMETRIC LONGITUDINAL TRANSLATION OF STAGE 1 SRB'S



- MODE IS PRIMARY INDICATOR OF DYNAMIC RESPONSE OF DRAG STRUTS (i.e., SRB'S ACTING AS RIGID BODIES)
- MODE FREQUENCY IS 2.3 HZ

Figure 4.2.2-3. Drag Strut Stiffness Verification

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frequency of approximately 0.5 Hz.) It is anticipated that the use of a complex dynamics model will yield a somewhat reduced first-mode frequency. Hence, the drag strut sizing based on strength requirements is regarded as marginal with respect to stiffness considerations.

Stiffness verification of the lateral struts is shown in figure 4.2.2-4. Sizing of lateral struts (both forward and aft) is derived from stiffness considerations. Preliminary sizing of the struts occurred prior to the use of a dynamics model. The effort defined a relative stiffness requirement between forward and aft lateral struts and provided an approximation to strut stiffness. Final sizing of the struts was accomplished via the simplified dynamics model. The result is a second flexible body mode, which is an asymmetrical combined translation/rotation (in pitch plane) of stage 1 SRB's. As such, the mode is a primary indicator of the dynamic response of the lateral struts. The mode frequency is 2.4 Hz.

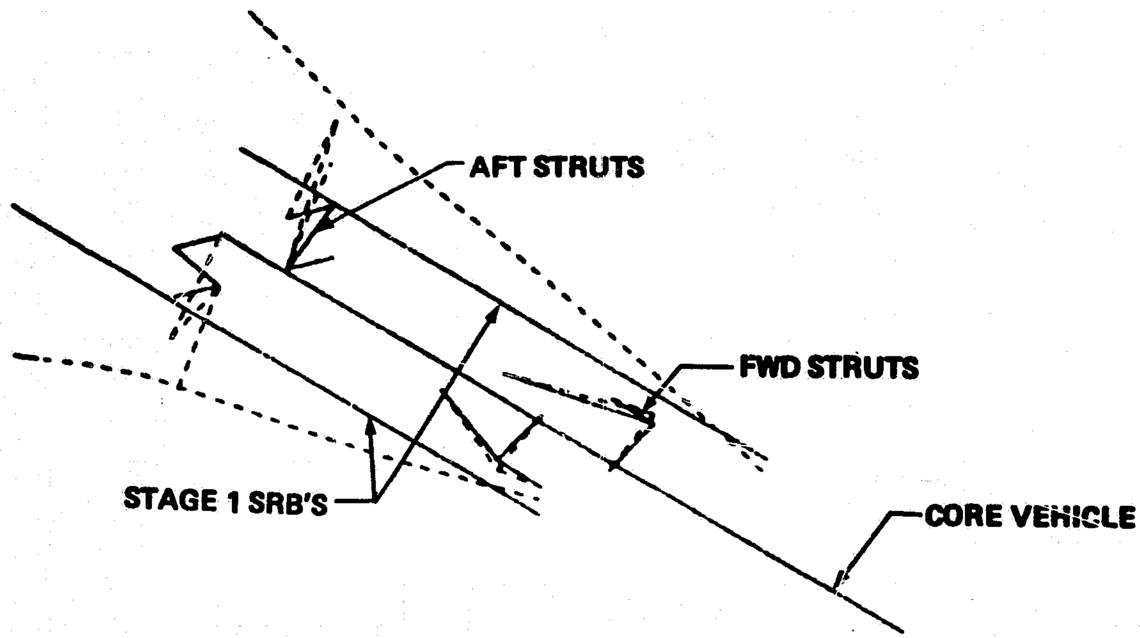
Design Features and Characteristics. Characteristics of the strut tubes, based on combined load and stiffness considerations for the drag struts and on stiffness considerations only for the lateral struts, are presented in table 4.2.2-3. Selected tube section reference diameters were 12 in for the drag strut and the aft lateral center strut and 10 in for the forward and aft lateral upper and lower struts. Ultimate tension and compression load-carrying capabilities of the tube sections are indicated. It should be noted that the weights data do not include provisions for end fittings, etc., which are discussed in subsequent paragraphs.

The weight estimate for the SRB-X strut end fittings, separation bolts, etc., relied heavily on the data base provided by the shuttle (STS), which is indicated in table 4.2.2-4. For the STS, the SRB external tank aft structural interface consists of three struts (lower, upper, and center) of identical design. All are 34 in long (pin-to-pin) and are designed for -299/+393 kips limit load (-419/+550 kips ultimate load). All struts use common components, but only the upper strut incorporates umbilical provisions. Component weights are indicated.

The weight data for strut clevis fittings, separation bolts, etc., at a design tension load of 550 kips ultimate are indicated in table 4.2.2-5. The data derive directly from STS strut data. SRB-X application of these data assumes that weight is directly proportional to ultimate design load.

The total weight and load capability for the forward strut system is shown in table 4.2.2-6. With respect to tension load capability, the data summarize, for each lateral strut and for the drag strut, the ultimate load capability of tube section, end (clevis)

- SECOND FLEXIBLE BODY MODE IS ASYMMETRIC COMBINED TRANSLATION/ROTATION (IN PITCH PLANE) OF STAGE 1 SRB'S



- MODE IS PRIMARY INDICATOR OF DYNAMIC RESPONSE OF LATERAL STRUTS (i.e., SRB'S ACTING AS RIGID BODIES)

MODE FREQUENCY IS 2.4 HZ

Figure 4.2.2-4. Lateral Strut Stiffness Verification

Table 4.2.2-3. Strut Tube Characteristics

- 5 CR–M_o–V STEEL
  - F_{TU} = 220,000 PSI (MIN)
  - P = 0.283 LB/IN^3
  - E = 29 X 10^6 PSI

		L (IN)	D (IN)	O.D. (IN)	I.D. (IN)	t (IN)	A (IN^2)	I (IN^4)	r_g (IN)	D/t	L/r_g	F_c (KSI)	T_{ULT} (KIPS)	C_{ULT} (KIPS)	w (LB/IN)	W [1] (LB)
FWD	DRAG STRUT	318.0	12	12.25	11.75	0.25	9.43	170	4.24	48	75	50	2075	472	2.675	850
FWD	LAT. UPR/LWR STRUT	122.5	10	10.10	9.90	0.10	3.14	39	3.54	100	35	135	691	424	0.889	109
AFT	LAT. UPR/LWR STRUT	140.7	10	10.125	9.875	0.125	3.93	49	3.53	80	40	124	864	487	1.112	157
AFT	LAT. CENTER STRUT	165.5	12	12.188	11.812	0.188	7.09	128	4.24	64	39	150	1560	1063	2.006	332

[2] (D through A)

[1] UNFACTORED TUBE WEIGHT (NO PROVISIONS FOR INSTALLING CLEVIS FITTINGS AND SEPARATION BOLTS).

[2] SELECTED SIZING OF LATERAL STRUT TUBES WHERE CROSS SECTION AREA DERIVES FROM STIFFNESS CONSIDERATIONS

Table 4.2.2-4. *Reference STS Strut Data*

- ALL STRUTS (LOWER, UPPER, CENTER) ARE 34 INCH LONG (PIN-TO-PIN), AND ARE DESIGNED FOR LOADS OF -299/+393 KIPS LIMIT (-419/+550 KIPS ULTIMATE)
- ALL STRUTS USE COMMON COMPONENTS, BUT ONLY THE UPPER STRUT INCORPORATES UMBILICAL PROVISIONS

	SRB SIDE	ET SIDE	TOTAL
BASIC STRUT	(33.9)	(38.9)	(72.8)
END FITTINGS, SEP BOLT, ETC.	(145.3)	(72.1)	(217.4)
CLEVIS	68.1	32.2	100.3
SEP BOLT	32.6	25.2	57.8
BOLT, NUT, WASHER	9.8	6.9	16.7
ADJUST NUT	27.0	—	27.0
SPH BEARING	4.2	—	4.2
RET & BKT	0.9	—	0.9
WASHER	1.2	—	1.2
NUT	—	7.4	7.4
ENERGY ABSORBER	1.5	0.4	1.9
ELECTRICAL, TPS	(4.6)	(3.0)	(7.6)
WIRING CONNECTORS & BKTS	1.1	1.0	2.1
INSULATED COVER	3.5	2.0	5.5
CENTER STRUT, LOWER STRUT	183.8	114.0	297.8
UMBILICAL PROVISIONS WEIGHT DELTA	(50.5)	(34.6)	(85.1)
MODS TO BASIC STRUT	16.0	17.4	33.4
RING	14.1	—	14.1
WIRING CONNECTORS & BKTS	4.7	—	4.7
INSULATED COVER	15.7	17.2	32.9
UPPER STRUT	234.3	148.6	328.9

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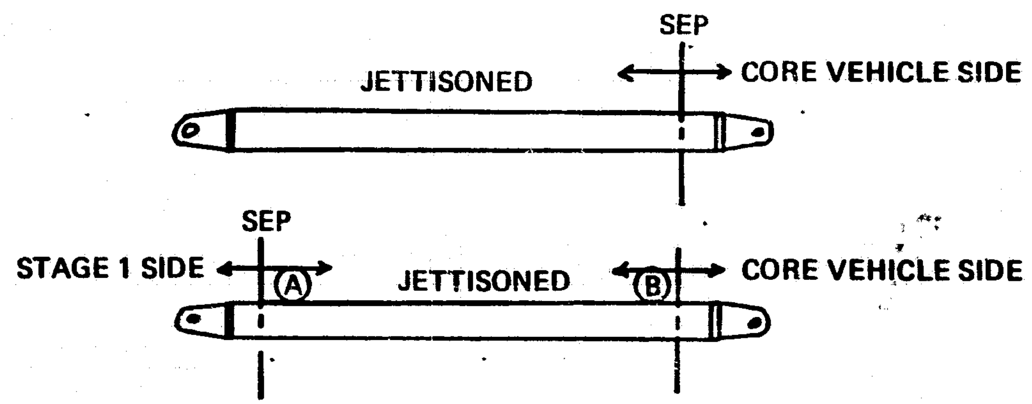
Table 4.2.2-5. Reference Weight Data—Forward and Aft Struts

DESIGN TENSION LOAD OF 550 KIPS ULTIMATE

FORWARD STRUT

AFT STRUT



	FORWARD STRUT		AFT STRUT			
	JETTISONED	CORE VEHICLE SIDE	STAGE 1 SIDE	JETTISONED Ⓐ	JETTISONED Ⓑ	CORE VEHICLE SIDE
CLEVIS	68	32	68	—	—	32
SEP BOLT	32	25	32	25	32	25
BOLT, NUT, WASHER	10	7	10	7	10	7
ADJUST NUT	27	—	27	—	—	—
SPN BEARING	4	—	4	—	—	—
RET AND BKT	1	—	1	—	—	—
WASHER	1	—	1	—	1	—
NUT	—	7	—	7	—	7
ENERGY ABSORBER	2	1	2	1	2	1
	145	72	145	40	45	72
				85		

Table 4.2.2-6. Forward Strut System Load Capability and Weight

	ULT TENSION LOAD CAPABILITY~KIPS		
	TUBE SECTION	END FTG	SEP BOLT
LATERAL STRUTS (10-IN DIA)	691	864*	864*
DRAG STRUT (12-IN DIA)	2075	2075	2075

*USING AFT UPR/LWR STRUT COMPONENTS

	WEIGHT PER SIDE ~LB			
	STAGE 1 RETAINED	JETTISONED	CORE VEHICLE RETAINED	TOTAL
THRUST FITTING	—	600	—	600
THRUST FITTING BALL, SEP BOLT, ETC.	160*	40*	—	200
DRAG STRUT TUBE SECTION	—	890	80	970
DRAG STRUT END FTGS, SEP BOLT, ETC.	—	540	270	810
LATERAL UPR STRUT TUBE SECTION	—	110	40	150
LATERAL UPR STRUT END FTGS, SEP BOLT, ETC.	—	230	115	345
LATERAL LWR STRUT TUBE SECTION	—	110	40	150
LATERAL LWR STRUT END FTGS, SEP BOLT, ETC.	—	230	115	345
ALLOWANCE FOR TPS, ELECTRICAL	20	80	30	130
TOTAL	180	2830	690	3700

*STS HARDWARE

TOTAL SYSTEM WEIGHT = 7400 LB

fittings, and separation bolts. To reduce from four to two the total number of end fittings and separation bolts to be designed, the forward lateral strut (10-in diameter) uses end fittings and separation bolts sized for the aft upper and lower lateral struts (also 10-in diameter). The weights data include those for the tube sections with provisions for end fittings, as well as the required end fittings. Each side of the forward strut system weighs 3700 lb, resulting in 7400 lb for the complete system.

The load capability and weights for the aft strut system are presented in table 4.2.2-7. In keeping with the goal of reducing from four to two the total number of end fittings and separation bolts to be designed, the aft center strut (12-in diameter) uses end fittings and separation bolts sized for the drag strut (also 12-in diameter). Each side of the aft strut system has a weight of 3300 lb, resulting in a total weight of 6600 lb.

4.2.2.2 Payload Shroud

Design Concept and Approach. The structural analysis described in section 3.5.2 indicated that stage 3, stage 4, and the payload would all be enclosed within a shroud. The configuration concept for the shroud is shown in figure 4.2.2-5. For analysis purposes, the shroud has been divided into the three indicated sections. Payload axial loads are transmitted via the upper stages to the second stage. Shroud axial loads are transmitted via the shroud to the second stage. A fixed portion of the shroud lateral load (20,000 lbf) is transferred to the upper stages via the FBR (753 in aft of nose). The forward component of the stage 1 force couple, which provides the necessary aerobalance, is transferred to the core vehicle and shroud via the forward interconnecting lateral struts (1132 in aft of nose). The forward force component is of 38,000 lbf magnitude.

The approach used to analyze the shroud is indicated in table 4.2.2-8. Key features include:

a. Max q-alpha = 5000 psf-deg.
b. Incorporation of Centaur FBR.
c. Use of Lockheed's Titan/Centaur shroud as data base for structures design (skin panels) and weights.

Design Considerations. Design considerations associated with the shroud analysis included upper stage bending characteristics, shroud loads, and deflections. Bending characteristics of the upper stages are indicated in figure 4.2.2-6. The quasi-steady-state bending moment applied to the upper stages results from the FBR of 20,000 lbf, with minor load relief provided by the lateral load factor of 0.12g. The maximum moment is

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Table 4.2.2-7. Aft Strut System Load Capability and Weight

	ULT. TENSION LOAD CAPABILITY ~ KIPS		
	TUBE SECTION	END FTG	SEP BOLTS
UPR/LWR STRUTS (10-IN DIA)	864	864	864
CENTER STRUT (12-IN DIA)	1560	2075*	2075*

*USING DRAG STRUT COMPONENTS

	WEIGHT (PER SIDE) ~ LB			
	STAGE 1 RETAINED	JETTISONED	CORE VEHICLE RETAINED	TOTAL
LOWER STRUT TUBE SECTION	45	130	45	220
LOWER STRUT END FTGS, SEP BOLTS, ETC	230	135	115	480
UPPER STRUT TUBE SECTION	70 } *	180 } *	70 } *	320
UPPER STRUT END FTG, SEP BOLTS, ETC.	250 }	155 }	135 }	540
CENTER STRUT TUBE SECTION	80	290	80	450
CENTER STRUT END FTGS, SEP BOLTS, ETC.	540	320	270	1130
ALLOW FOR TPS, ELECTRICAL	25	110	25	160
TOTAL	1240	1320	740	3300

*DELTA WEIGHT RELATIVE TO LOWER STRUT REFLECTS STRUCTURAL MODS TO ACCOMMODATE STAGE 1 UMBILICAL

TOTAL SYSTEM WEIGHT = 6600 LB

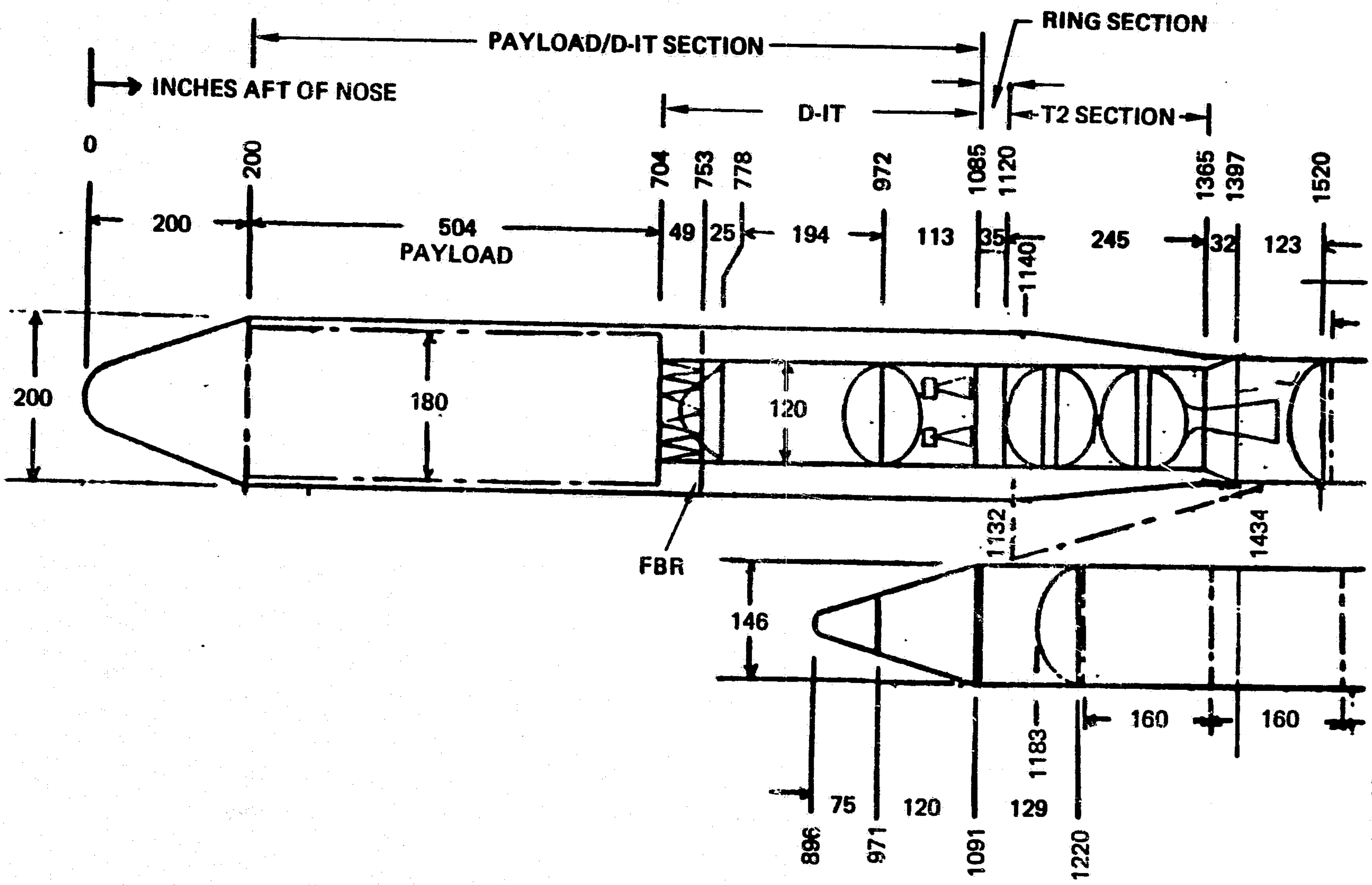

Figure 4.2.2-5. Shroud Configuration

Table 4.2.2-8. *Shroud Design Approach*

- USE GEO MISSION SHROUD FOR STRUCTURAL DESIGN PURPOSES

- DEFINE LOAD REQUIREMENTS FOR UPPER STAGES AND SHROUD
  - STRUCTURAL DESIGN MAX $q\alpha$ = 5000 PSF-DEG
  - FBR SHEAR PLANE LIMIT LOAD CAPABILITY = 20,000 LBF

- DETERMINE UPPER STAGES DEFLECTION AT THE FBR

- DETERMINE ALLOWABLE SHROUD DEFLECTION AT THE FBR
  - FBR SPRING CONSTANT = 20,000 LB/IN.

- DETERMINE THE LIGHTEST WEIGHT SHROUD SKIN PANELS (BETWEEN THE FBR AND STAGE 2 FORWARD SKIRT) WHICH SATISFY MINIMUM GAGE, STRENGTH AND DEFLECTION (i.e., STIFFNESS) REQUIREMENTS
  - USE LOCKHEED SKIN PANEL DESIGN DATA

- USE THE LOCKHEED TITAN/CENTAUR SHROUD (58.5 FT LENGTH, 14 FT. DIA.) AS A DATA BASE FOR DEFINITION OF SHROUD COMPONENTS OTHER THAN THE SKIN PANELS (AND RING ASSEMBLY)

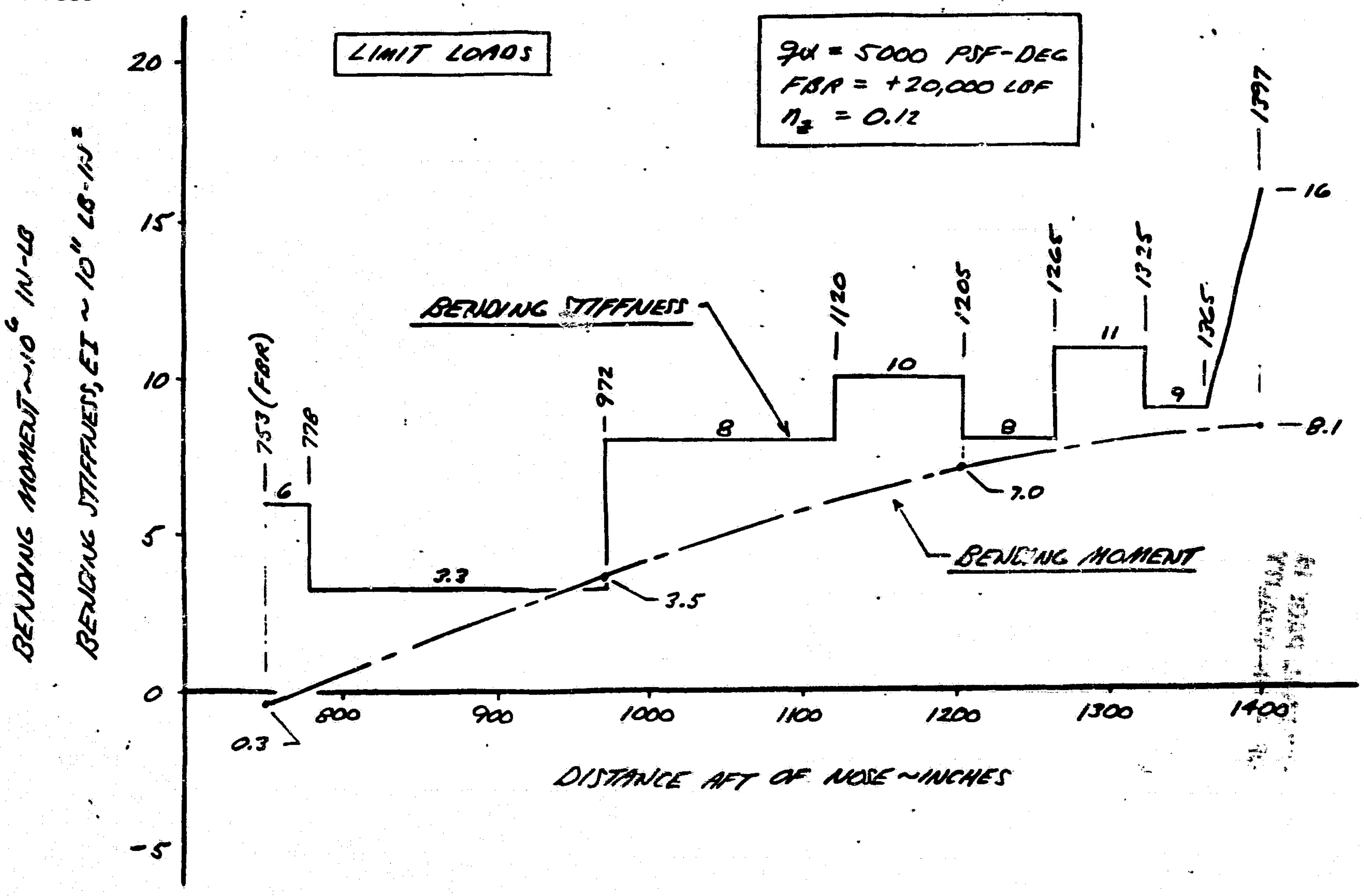

Figure 4.2.2-6. Bending Characteristics of Upper Stages

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8.1×10^6 in-lb and occurs at the base of the stage 2-3 interstage (1397 in aft of nose). The bending stiffness of the D-IT and T2 stages is as indicated, where the T2 stage stiffness is a simplified approximation of a more complex distribution provided by Martin Marietta.

The quasi-steady-state loads (axial load, shear, and bending moment) applied to the shroud are indicated in figure 4.2.2-7. Bending is the primary load condition and results from the aerolift on the nose of 39,000 lbf, with substantial load relief provided by the FBR of 20,000 lbf and the stage 1 forward lateral force component of 38,000 lbf, and with minor load relief provided by the lateral load factor of 0.12g. The maximum moment is 35×10^6 in-lb and occurs at the location of the stage 1 forward lateral force component (1132 in aft of nose).

The final design consideration was the deflections occurring in the shroud sections surrounding the T2 and D-IT. These data are presented in figure 4.2.2-8. The maximum allowable shroud deflection at the FBR is 2.5 in and results from the upper stages deflection (at the FBR) of 1.5 in, combined with a 1.0-in deflection lag across the FBR (due to its spring constant of 20,000 lbf/in). This deflection limit can be satisfied by various distributions of skin panel $\bar{t}$'s aft of the FBR. A practical design approach was adopted in which the D-IT section and the T2 section skin panel $\bar{t}$'s were held constant within each section. Using this approach, minimum total skin panel weight is obtained with a D-IT section $\bar{t}$ of 0.74 in and a T2 section $\bar{t}$ of 0.17 in. (Skin panels located forward of the FBR have a $\bar{t}$ of 0.059 in, based on minimum gage requirements.)

Design Features and Characteristics. Based on considerations of manufacturing, handling, and accessibility to equipment within, the shroud was divided into sections as indicated in figure 4.2.2-9. The indicated GEO shroud accommodates a 42-ft payload and the LEO shroud, a 60-ft payload, although other lengths are possible.

Skin thickness and weight data for the various shroud sections are presented in table 4.2.2-9. The thickness combinations for the basic skin and corrugation of sections B through H derive from Lockheed skin panel design data. Sections J and K utilize stringer-stiffened skin panels. The unit weights for "other structural assembly items" and thermal provisions derive from Lockheed's Titan/Centaur shroud. The unit weight for "other structural assembly items" considers the larger shroud diameter (16.7 ft compared to 14.0 ft), the use of three rather than two longitudinal separation joints in the payload/ D-IT sections, and other structural definition peculiarities. Design features of the ring assembly (shroud section I) are shown in figure 4.2.2-10 and discussed in the following

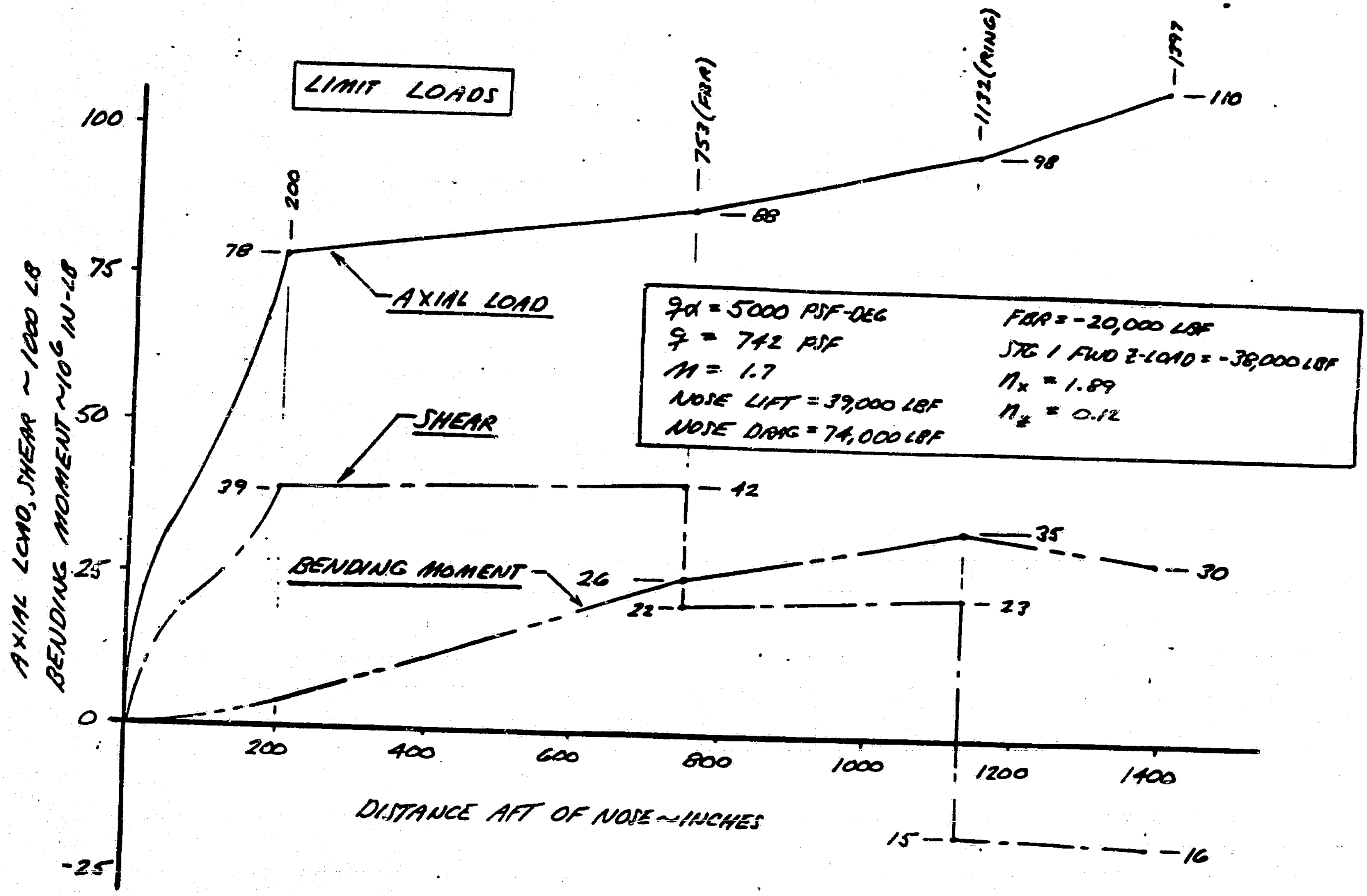

Figure 4.2.2-7. Shroud Loads

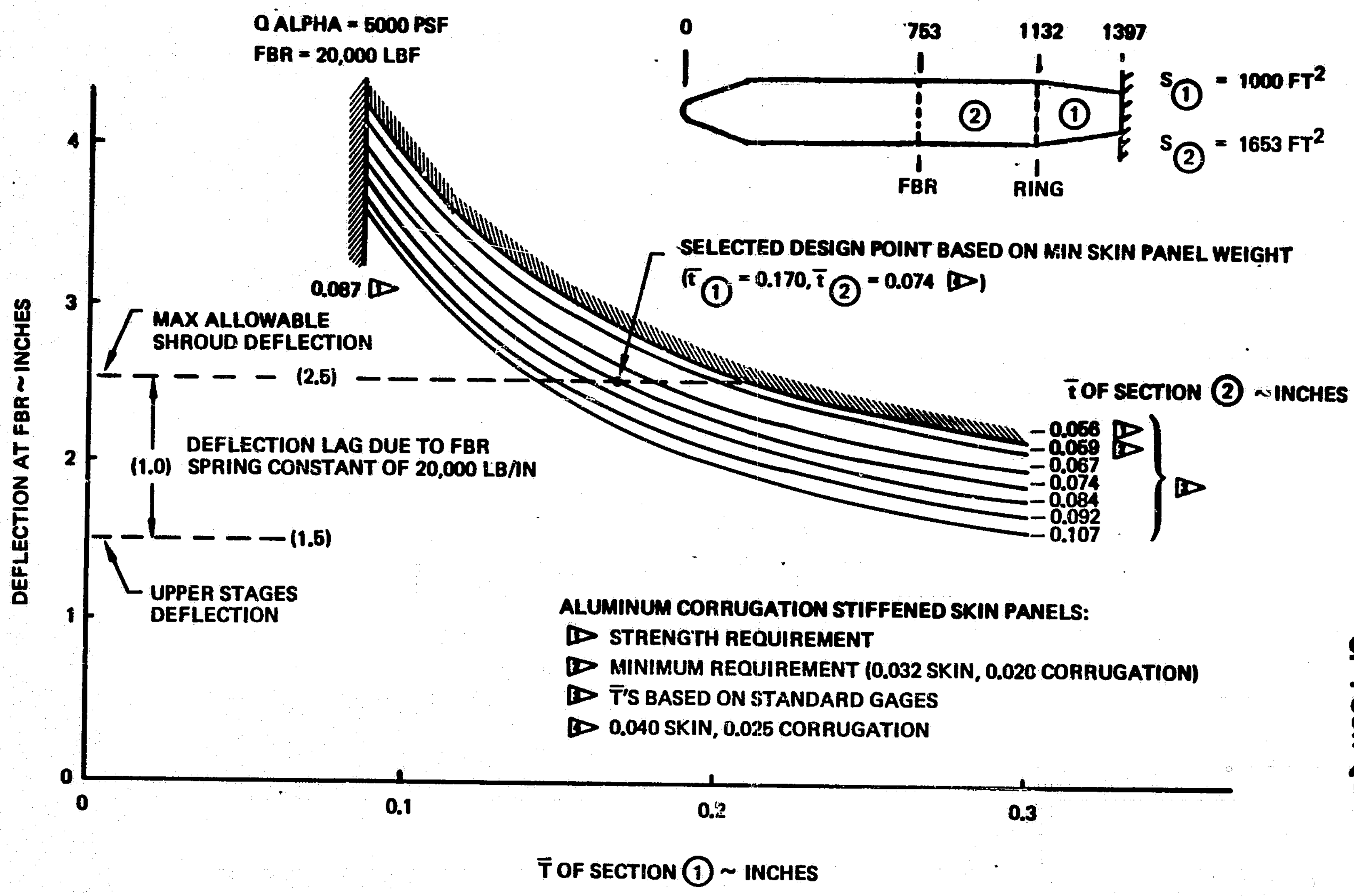

Figure 4.2.2-8. Selection of Shroud Skin Panel t̄'s

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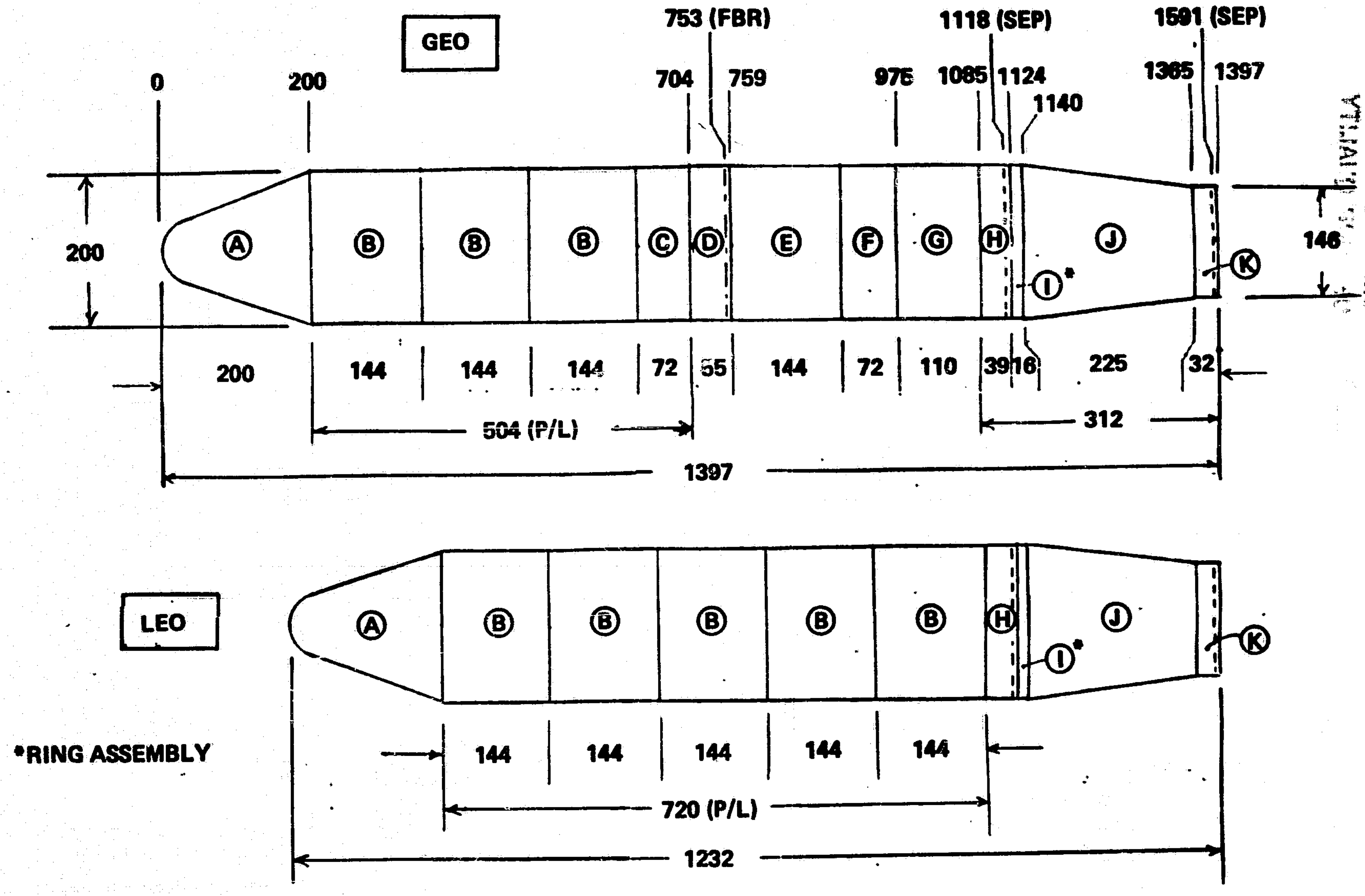


Figure 4.2.2-9. Shroud Sections

SRB-X-335

Table 4.2.2-9. *Shroud Sections Skin Thickness and Weight*

	A	B	C	D	E	F	G	H	I	J	K
SKIN THICKNESSES (INCH)											
BASIC SKIN		0.032	0.032	0.040	0.040	0.040	0.040	0.040			
CORRUGATION		0.020	0.020	0.025	0.025	0.025	0.025	0.025			
(TOTAL t)		(0.059)	(0.059)	(0.074)	(0.074)	(0.074)	(0.074)	(0.074)		(0.170)	(0.170)
UNITS WEIGHTS (LB/FT^2)											
SKIN PANELS [1]		0.85	0.85	1.07	1.07	1.07	1.07	1.07		2.45	2.45
OTHER STRUCT ASSY ITEMS		1.05	1.05	1.11	1.05	1.05	1.11	2.16		1.55 [illegible]	3.90
THERMAL PROVISIONS [2]		0.20	0.20	0.20	0.55	0.55	0.20	0.20		0.20	0.20
WEIGHT MARGIN		0.10	0.10	0.12	0.13	0.13	0.12	0.17		0.20	0.25
(TOTAL)	(3.2)	(2.2)	(2.2)	(2.5)	(2.8)	(2.8)	(2.5)	(3.6)		(4.4)	(5.9)
SURFACE AREA (FT^2)	625	628	314	240	628	314	480	170	70	866	102
WEIGHT (LB)	2000	1380	690	600	1760	880	1200	610	[4] 2320	3760	600 [illegible]

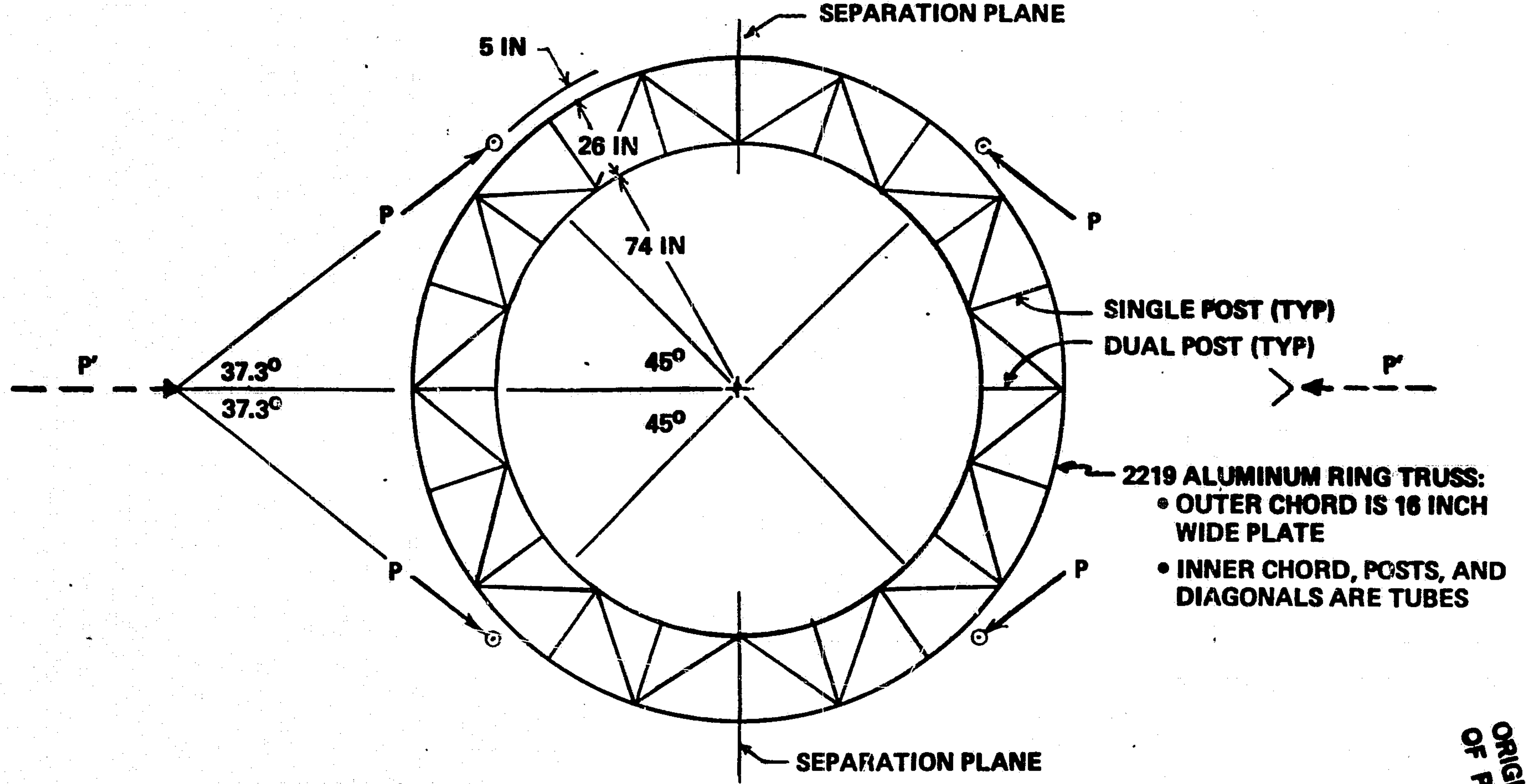
[1] STABILITY RINGS, JOINTS (FIELD, PRODUCTION, SEPARATION), PYROTECHNICS, MECHANISMS, ACCESS PROVISIONS, UMBILICAL PLATES, ETC.

[2] THERMAL LINERS, BLANKETS

[3] INCLUDES KICK RING AT LOWER END (220 LB)

[4] NON-SEPARABLE WEIGHT APPROX. 250 LB (STRUCTURE & MECHANISMS)

- DESIGN FOR Y-DIRECTION COMPRESSIVE LOADS BASED ON MAXIMUM COMPRESSION LOAD CAPABILITY OF FORWARD LATERAL STRUTS.



P = -339 KIPS LIMIT (-424 KIPS ULTIMATE)

P' = -539 KIPS LIMIT (-674 KIPS ULTIMATE)

Figure 4.2.2-10. Shroud Ring Assembly

paragraph. Total shroud weight is 18,560 lb for the GEO mission (42-ft payload) and 16,190 lb for the LEO mission (60-ft payload).

The shroud ring assembly is designed to carry (internally) Y-direction compressive loads defined by the maximum compression load capability of the forward lateral struts. The basic ring is a 26-in-deep ring truss in which the outer chord is a 16-in-wide plate, and the inner chord, posts, and diagonals are tubes. It is a welded assembly constructed of 2219 aluminum. The ring assembly incorporates pyrotechnics and mechanisms to effect a clamshell separation of the combined ring assembly and T2 shroud, plus external fittings for attachment of the forward lateral interconnecting struts. Total weight is 2320 lb, distributed as follows: basic ring truss at 1500 lb, pyrotechnics and mechanisms at 500 lb, and external fittings at 320 lb.

4.2.2.3 Stage 2 Forward Skirt Design Approach and Weight

The stage 2 forward skirt is a modified STS SRB forward skirt. A summary of the modifications and weight impact is shown in table 4.2.2-10. The most significant modifications include the addition of (1) a second thrust post and thrust post fitting (opposite the existing post and fitting), (2) a new kick ring to react the lateral force component of the drag strut loads, and (3) new external fittings for drag strut attachment. Total weight of the modified skirt is 7800 lb—an increase of approximately 1540 lb.

4.2.2.4 Stage 1 and 2 SRM Stiffness

As noted in section 4.2.2.1, the first and second flexible body modes verified the stiffness of the drag struts and lateral struts, respectively. In these first two modes, both the stage 1 SRB's and the core vehicle acted as rigid bodies. The lowest mode in which stage 1 SRM sidewall bending stiffness is a dominant factor is the third flexible body mode. As indicated in figure 4.2.2-11, this mode is asymmetrical bending (in the pitch plane) of stage 1 SRB's. Mode frequency is 2.8 Hz with lightweight steel cases, which would be reduced to 2.5 Hz with filament wound cases. Frequency with either type of SRM case is above the goal of 2 Hz, which provided a factor of 4 relative to the flight control frequency.

In the first three flexible body modes, the core vehicle acted as a rigid body. However, the fourth flexible body mode is bending (in the pitch plane) of the core vehicle relative to translation of stage 1 SRB's, as shown in figure 4.2.2-12. This is the lowest mode in which stage 2 SRM sidewall bending stiffness is a dominant factor. Mode frequency is 3.3 Hz with lightweight steel cases, reducing to 2.9 Hz with filament wound cases. Again, the resulting frequencies are above the goal of 2 Hz.

Table 4.2.2-10. *Stage 2 Forward Skirt Design Approach and Weight*

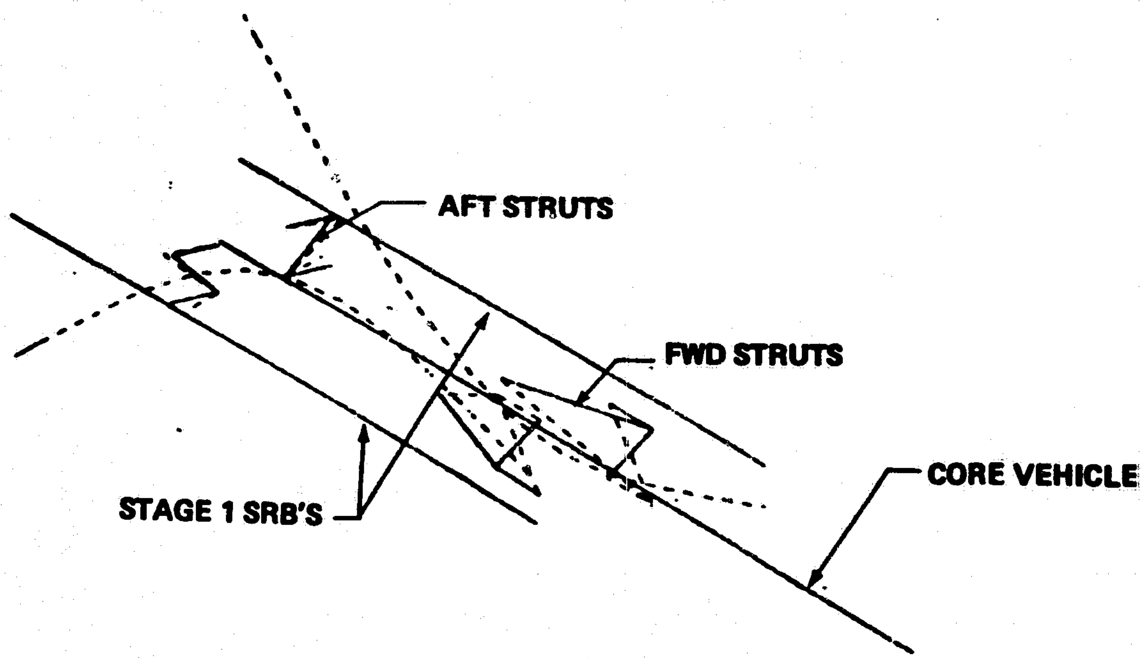
- **MODIFIED STS SRB FORWARD SKIRT**

STS SRB FWD SKIRT (EXCL SRB/ET ATTACH PROVISIONS [1])	6256
DELETE 67° SKIN SEG OPPOSITE EXISTING THRUST POST	- 470
ADD ADDITIONAL THRUST POST & THRUST POST FTG	+1092
DELETE RING SEGMENTS AT/NEAR STA 445	-100
ADD NEW KICK RING AT STA 445 [2]	+854
DELETE FORWARD BULKHEAD	-332
ADD NEW EXTERNAL FTGS FOR DRAG STRUT ATTACH	+500
SRB-X STAGE 2 FWD SKIRT	7800 LB

[1] INCLUDED AS PART OF INTERCONNECTING STRUTS

[2] REACTS DRAG STRUT LATERAL LOAD COMPONENT OF +414 KIPS LIMIT, +518 KIPS ULTIMATE, PER SIDE (LIFTOFF TRANSIENT). USING 28-INCH DEEP I-BEAM OF 2219 ALUMINUM.

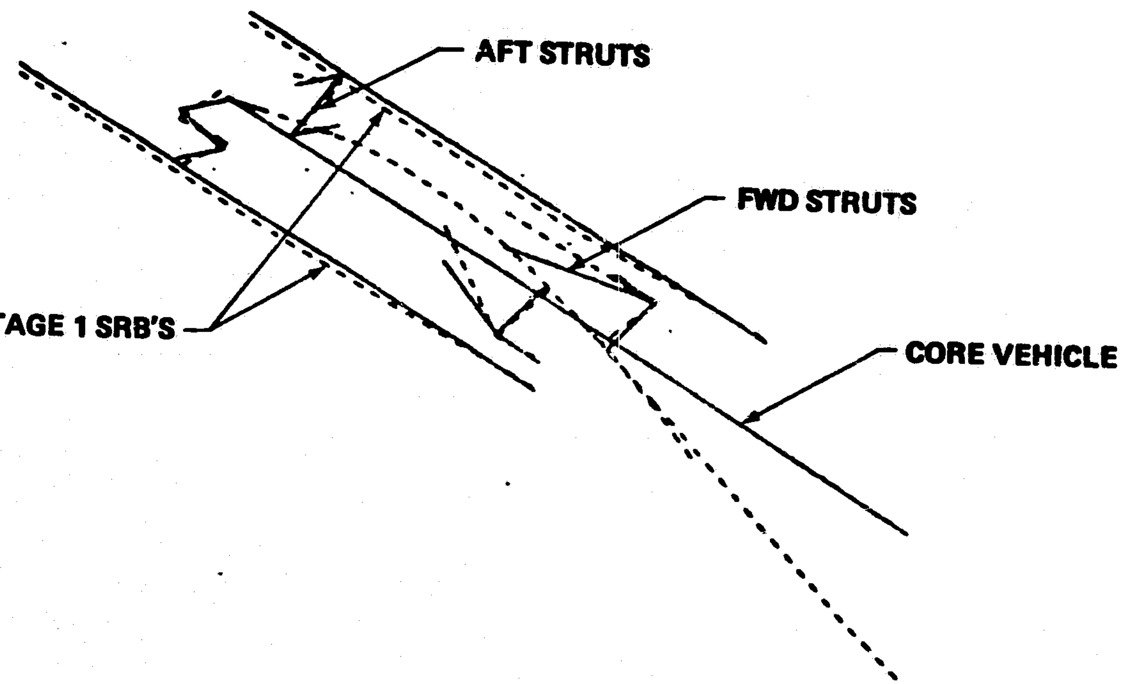
- THIRD FLEXIBLE BODY MODE IS ASYMMETRIC BENDING (IN PITCH PLANE) OF STAGE 1 SRB'S



- MODE IS PRIMARY INDICATOR OF DYNAMIC RESPONSE OF STAGE 1 SRB'S (i.e., CORE VEHICLE ACTING AS RIGID BODY)
- MODE FREQUENCY IS
  - 2.8 HZ; LIGHTWEIGHT STEEL SIDEWALLS
  - 2.5 HZ; FILAMENT WOUND SIDEWALLS

Figure 4.2.2-11. Stage 1 SRM Sidewall Bending Stiffness

- FOURTH FLEXIBLE BODY MODE IS BENDING (IN PITCH PLANE) OF CORE VEHICLE RELATIVE TO TRANSLATION OF STAGE 1 SRB'S.



- MODE IS PRIMARY INDICATOR OF DYNAMIC RESPONSE OF STAGE 2 SRB/TITAN SECTION OF SHROUD (i.e., STAGE 1 SRB'S ACTING AS RIGID BODIES)

- MODE FREQUENCY IS
  - 3.3 HZ; LIGHTWEIGHT STEEL SIDEWALL
  - 2.9 HZ; FILAMENT WOUND SIDEWALL

Figure 4.2.2-12. Stage 2 SRM Sidewall Bending Stiffness

4.2.3 Avionics Subsystem

The avionics subsystem for SRB-X is based on the maximum use of existing STS or other program hardware. It provides complete guidance and control for LEO delivery missions without an upper stage and accommodates guidance and control when furnished by an upper stage used for GEO missions. The avionics subsystem accomplishes the following functions:

a. Communications and tracking—provides the required radiofrequency (RF) link between the vehicle and other support elements; includes receiving commands, transmitting telemetry data, and turnaround of ranging signals.

b. Flight control— determines and controls vehicle attitude, velocity, and position; maintains vehicle stability; provides vehicle flight event control.

c. Data management—provides vehicle computation capability; collects, formats, and processes status data and distributes the data required for command and control.

d. Instrumentation—provides for the sensing of vehicle status; provides for signal conditioning of the sensed data as required and provides it to data management.

e. Range safety—provides the capability for command destruct of the vehicle as required to satisfy the safety requirements of the range.

4.2.3.1 Avionics Subsystem Design Rationale

The SRB-X concept is derived from existing STS SRB hardware elements to the greatest extent possible in providing a launch vehicle that satisfies the study objectives. The selected vehicle concept uses solids for the first two stages and a Titan second stage for the third stage. In the development of an avionics subsystem for the SRB-X launch vehicle, the following criteria were used:

a. For the SRB's for stage 1, avionics changes would be minimized to maintain interchangeability with the existing STS launch system. In addition, the existing STS SRB avionics interfaces would be the same for both STS and SRB-X.

b. Since the existing SRB's are designed to interface with shuttle avionics, orbiter-type equipment on other vehicle elements would be used to the extent feasible.

c. Use of new hardware component design would be minimized through existing suitable STS hardware; where suitable STS hardware does not exist, existing hardware from other programs would be used.

d. An integrated avionics subsystem design would be provided to accommodate the requirements of the total SRB-X launch vehicle.

e. Two operational modes would be accommodated: (1) self-provided guidance and control for LEO delivery missions and (2) guidance and control provided by upper stage.

f. Recovery of only the first-stage SRB's would be accomplished.

4.2.3.2 Functional Description

An overall block diagram of the SRB-X avionics subsystem is shown in figure 4.2.3-1. A major portion of the avionics is accommodated in the vehicle's control module, located immediately above stage 3. The design accommodates all of the design rationale discussed in the previous section. The following paragraphs discuss the design approach for each major functional area.

Communications and Tracking. The communications and tracking portion of the SRB-X includes a signal processor, an STDN/TDRSS transponder, a 20W S-band power amplifier, a diplexer, an RF switch, two power dividers, and four antennas. The signal processor selects and processes telemetry data from the data bus master controllers prior to providing the data to the transmitter portion of the transponder. The transponder receives uplink signals, turns around the ranging signal, and transmits downlink data signals to the RF power amplifier, which amplifies the transmit signal to a minimum level of 20W. The diplexer provides simultaneous uplink and downlink RF signal paths between the transponder and RF amplifier and the antennas. The RF switch is used to select antennas located on either the control module or the second stage. The power divider provides equal power to the omniantennas located diametrically opposite from each other.

Flight Control. As was previously discussed, the SRB-X flight control uses different designs to provide the two flight control modes (with and without upper stage guidance). For the case without upper stage guidance, a redundant inertial measurement unit is installed in the SRB-X control module. The inertial measurement unit electronics provide conditioned power, thermal control, digital control, synchronization, and the interface between the launch vehicle computers and the inertial sensors. The flight program is executed by the computers and includes stability control of the vehicle. System gain values are changed and filtering is performed as required for the differing flight conditions, such as configuration changes that occur as elements are staged. Flight control events, such as spent vehicle and shroud staging, are also generated by the computers.

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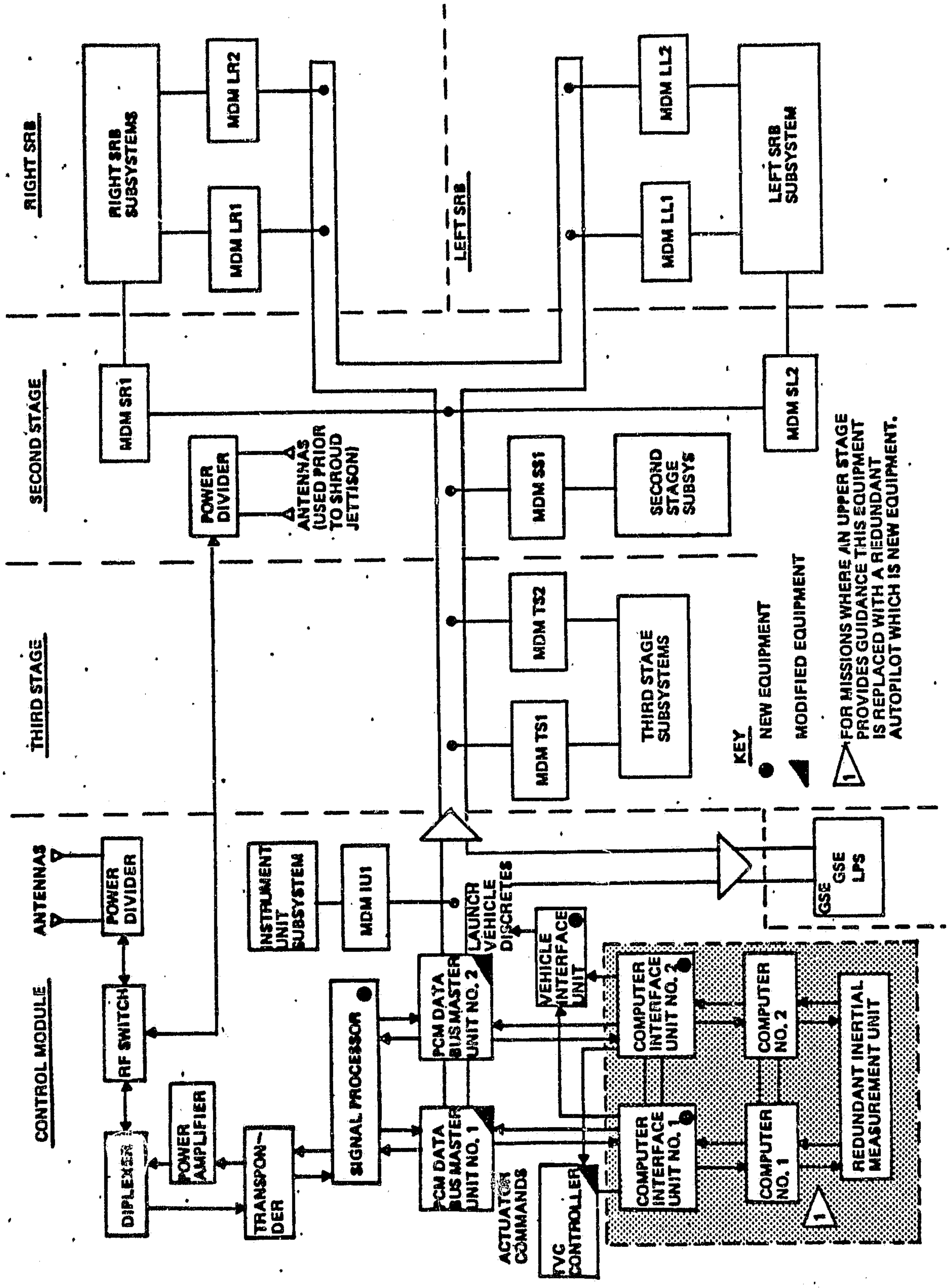

Figure 4.2.3-1. SRB-X Avionics Subsystem

For the case of upper-stage-provided guidance, the computers and inertial measurement unit are replaced by a digital autopilot in the control module. The autopilot provides stable vehicle control in response to guidance commands provided by the upper stage. System gains in the autopilot are changed as required. The launch vehicle events (separation, inflight engine start commands, etc.) are provided by an event controller driven by upper-stage-provided discrete commands.

For both modes of flight control, control of the servoactuators for the launch vehicle is provided by the TVC controller mounted in the vehicle control module.

Data Management. The data management system consists of the data bus system, the two flight computers and computer interface units (when required for the case of self-provided flight control), and the vehicle interface unit. The data bus system is the primary mode for all data acquisition and for the transmission from the computers of onboard-generated commands to the vehicle elements.

On the existing STS, there are a large number of wiring connections across the orbiter-SRB interface. The majority of these connections go to multiplexer-demultiplexers (MDM) on the orbiter side of the interface. In order to maintain STS and SRB-X stage 1 SRB commonality, MDM's are installed on SRB-X stage 2 to accommodate these interfaces.

For the case with no upper stage guidance, the computers are functionally independent and each executes an entire flight program. On the basis of computer self-tests, the computers provide OK status indications to the computer interface units. On initial power-up, one computer will be designated as prime and will control vehicle operations. The computer interface unit will control the redundancy management for the dual string operation. The computer that is in control will remain in control until the computer removes its status indication to the computer interface. Upon failure to receive correct status control indication from the computer in control, the computer interface unit will place the other channel in control.

In addition to the redundancy management function, the computer interface unit provides the interface electronics between all other vehicle elements (TVC controller, data bus, vehicle interface unit, transponder, spacecraft, etc.) and the computers.

The vehicle interface unit provides the interface between the data management portion of the SRB-X avionics and the other vehicle elements. It is used to provide discrete commands, such as separation and engine ignition, to other vehicle elements. The vehicle interface electronics unit is internally redundant.

Instrumentation. The instrumentation subsystem provides for the sensing of the state of vehicle subsystems and commands and for conditioning of the sensor outputs prior to the acquisition of the outputs by the data bus system.

Range Safety. The range safety system, in the event the vehicle deviates beyond prescribed limits of its flightpath or becomes a safety hazard to continue powered flight, provides a means for terminating the flight of the launch vehicle. The range safety system for each stage consists of a receiver decoder, antenna system, and ordnance.

4.2.3.3 Stage Avionics Description

A summary of the avionics associated with each stage is shown in figure 4.2.3-2 and discussed in the following paragraphs.

Stage 1. The avionics subsystem for stage 1 SRB's is unchanged from the design used on existing STS SRB's.

Stage 2. The avionics system for stage 2 consists of a single integrated electronics assembly to accomplish all avionics functions presently provided on the STS SRB's, with the exception of recovery. In addition, MDM's are added to interface the stage 1 SRB's with the rest of the vehicle. Stage 2 avionics also include provisions for pyrotechnic initiators for stage 1 separation, stage 2 and stage 3 separation, and stage 2 retromotors. A range safety system is also included and is cross-strapped to the range safety systems of the stage 1 SRB's (as is presently done on the ET and SRB's on the STS). Diametrically installed antennas and a power divider are also installed in the forward skirt of stage 2 to provide an RF link while the payload shroud covers the antennas installed on the control module. After the shroud is jettisoned, these antennas are switched out and the vehicle RF link is through the control module antennas.

Stage 3. The stage 3 avionics system includes the basic Titan second-stage complement of hardware. Stage 3 avionics are connected into the data bus through MDM's. A range safety and inadvertent separation system is also installed.

Control Module. The control module (sometimes referred to as the instrument unit) contains the vehicle RF link, data bus master units, TVC controller, vehicle interface unit, computers and their interface units, and the inertial measurement unit (for self-provided guidance) or vehicle autopilot (for upper-stage-provided guidance).

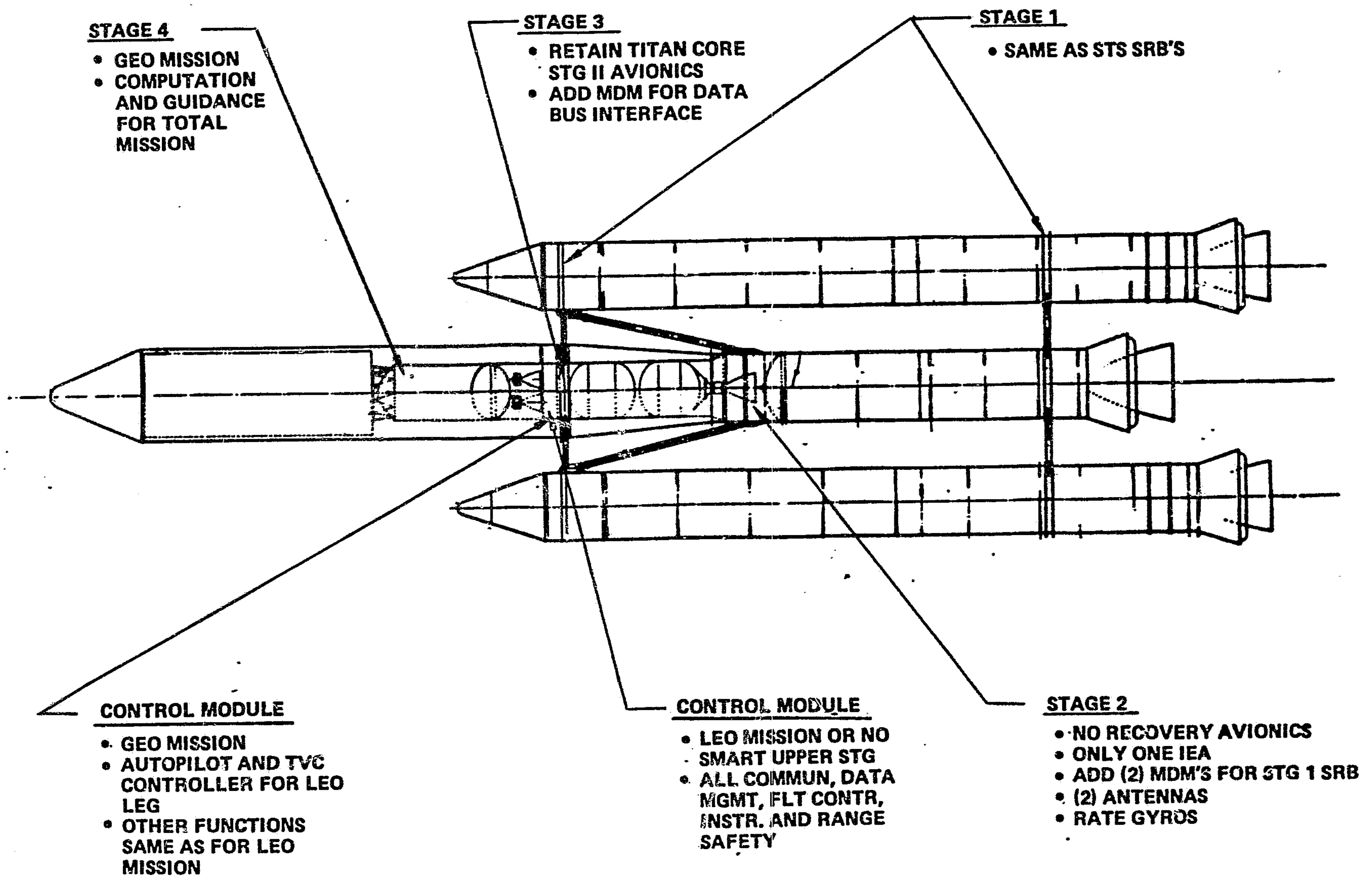

Figure 4.2.3-2. SRB-X Avionics Concept

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4.2.3.4 Equipment Heritage and Weight

The avionics system design is based on the use of existing equipment to the extent possible in order to minimize front-end DDT&E costs. The heritage and weight of the subsystem are shown in table 4.2.3-1. The majority of the equipment is installed on the control module and is derived from either STS or IUS hardware. The MDM's used on all of the stages are derived from the STS program. The integrated electronics unit on the second stage combines the functions of the forward and aft assemblies used on the first-stage SRB's, without the recovery system. For the third stage, there may be a requirement for a stage interface unit between the MDM's and the existing Titan second-stage avionics complement. This area was not fully explored during this study.

4.2.4 Stability and Control Analysis

A preliminary assessment of several SRB-X concepts was presented in section 3.5.4. The following material presents an overview of the scope of the effort and results concerning the selected SRB-X concept.

4.2.4.1 Overview

The control system studies of the SRB-X vehicle were conducted in three phases. The first consisted of static stability analysis of the vehicle in the pitch and yaw planes to establish the basic parameters within which the control system would operate. The second phase consisted of computer-aided linear analyses of the vehicle dynamics with control system at selected time points. These linear analyses established appropriate control system gains. The third phase consisted of studies conducted with a three-degree-of-freedom pitch plane time simulation of vehicle flight during the atmospheric portion of its mission. These studies answered questions about the control system's ability to follow a specified trajectory, the level of structural loading, and the gimbal requirements imposed on the stage 1 TVC. These three phases are discussed in the following paragraphs, along with the basic control philosophy employed.

4.2.4.2 Pitch and Yaw Static Stability

The pitch and yaw static stability of the basic SRB-X concept (B3) is shown below. These data indicate the vehicle had static stability with acceptable nozzle deflections at maximum dynamic pressure when subjected to an external wind disturbance.

Table 4.2.3-1. SRB-X Avionics Equipment Weight and Heritage

ITEM	WEIGHT (LB) LEO	WEIGHT (LB) GEO	EQUIPMENT HERITAGE
AVIONICS	775	530	
COMMUNICATIONS	74	74	
SIGNAL PROCESSOR (1)	35	35	NEW, STS DERIVED, EXCLUDES ENCRYPTER/DECRYPTER
TRANSPONDER (1)	14	14	IUS
POWER AMPLIFIER (1)	12	12	IUS
ANTENNA INSTALLATION	13	13	IUS DERIVED
DATA MANAGEMENT	287	106	
COMPUTER (2)	103	—	IUS
COMPUTER INTERFACE UNIT (2)	80	—	NEW, IUS DERIVED
MULTIPLEXER/DEMULTIPLEXER(1)	34	34	STS
PCM DATA BUS MASTER UNIT (2)	56	56	MODIFIED STS
ISOLATION AMPLIFIER (2)	16	16	STS
FLIGHT CONTROL	274	272	
REDUNDANT IMU (1)	92	—	IUS
AUTOPILOT (1)	—	90	NEW
VEHICLE INTERFACE UNIT (1)	26	26	IUS DERIVED
TVC CONTROLLER (4)	156	156	MODIFIED STS
INSTRUMENTATION	35	35	
DEDICATED SIGNAL CONDITIONER (1)	20	20	NEW, STS DERIVED
SENSORS	15	15	STS DERIVED
RANGE SAFETY	103	103	STS ET DERIVED—INCLUDES RANGE SAFETY BATTERIES

Parameter	Pitch	Yaw
Max dynamic pressure (psf)*	800	800
V_{WIND} (ft/sec)*	260	260
$V_{VEHICLE}$	1362	1362
CP-CG (ft)	33	66
Gimbal plane--CG (ft)	68	68
Induced alpha (deg)	10.08	10.08
Margin TVC/wind torque	3.04	2.34
Gimbal angle to balance (deg)**	1.56	2.02

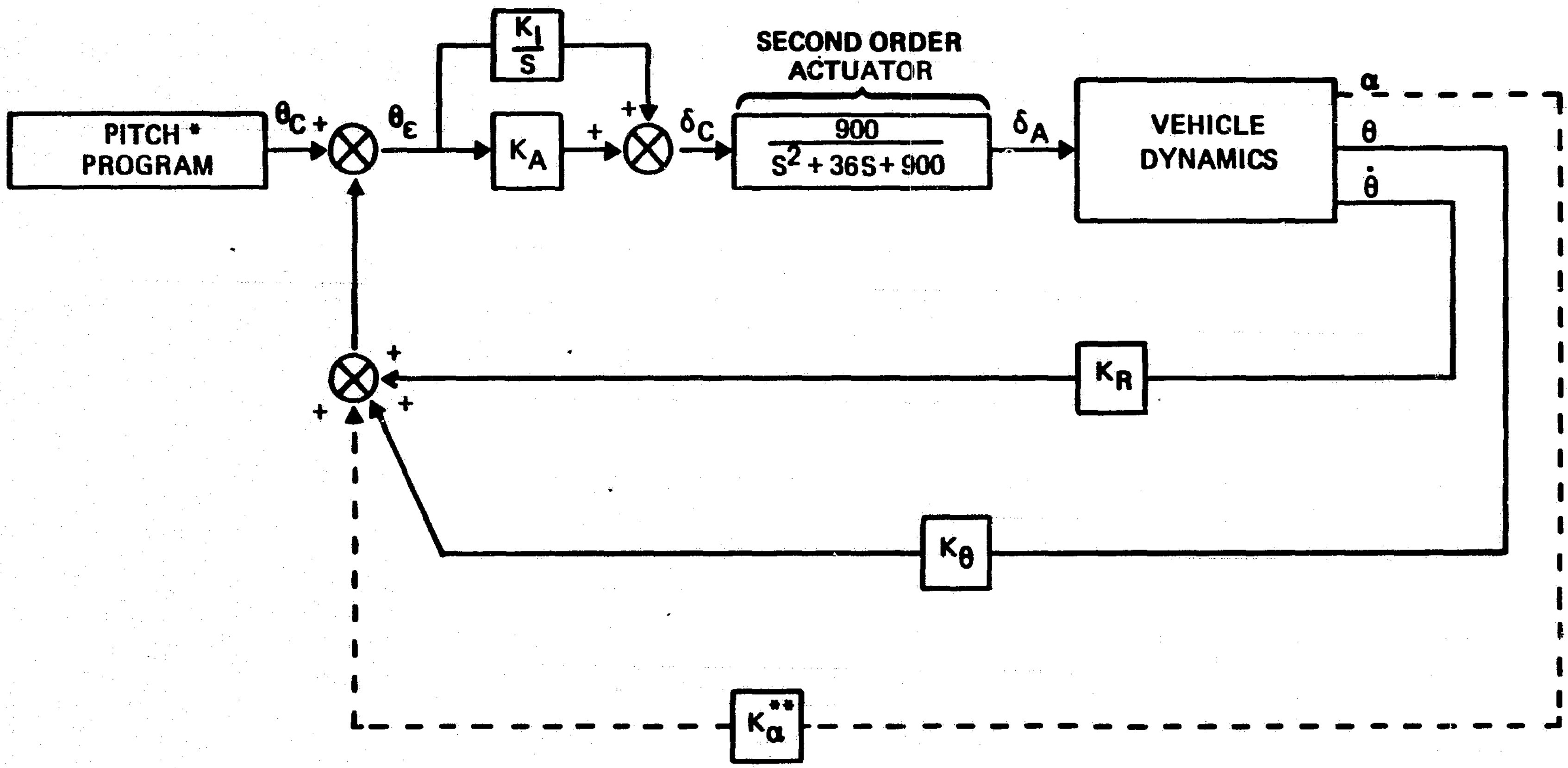
*WTR winds (95%) with gust of 50 fps.

**Maximum gimbal allowed = 4.75 deg.

4.2.4.3 Control System Concepts

A simplified block diagram of the control system is shown in figure 4.2.4-1. Three variations of the control system were simulated. The first combined a standard attitude/rate autopilot with a pitch program designed to fly a trajectory and assumes the wind profile is known. The second combined a standard attitude/rate autopilot with a pitch program designed to fly a trajectory without knowing the precise wind profile to be encountered. The third involved an autopilot that had an angle-of-attack feedback loop added to the attitude/rate loops and assumed there was no knowledge of the wind profile. This additional angle-of-attack feedback loop makes the control system more responsive to winds and helps reduce structural loading by acting to keep the angle of attack small during periods of high dynamic pressure. However, use of angle-of-attack feedback also causes some degradation in the control system's trajectory-following capabilities. Since the control system is designed to be sensitive to wind disturbances through the angle-of-attack feedback loop, the pitch program assuming no knowledge of winds was used.

Gains were set for several critical time points during atmospheric flight. These gains were established by doing linear analyses about the operating conditions at the various time points and using engineering judgment on good dynamic response. The gains for all three control system variations are shown in table 4.2.4-1. These gain schedules were not optimized and system performance could be improved with more comprehensive analysis.



* THERE ARE TWO DISTINCT PITCH PROGRAMS, ONE ASSUMES NO KNOWLEDGE OF WINDS, THE OTHER ASSUMES THE WINDS ARE KNOWN

** THE ANGLE OF ATTACK FEEDBACK LOOP IS ADDED TO INSURE THAT STRUCTURAL LOADING IS REDUCED

Figure 4.2.4-1. Control System Block Diagram

Table 4.2.4-1. Control System Gains

GAIN SCHEDULE FOR NO WIND TRAJECTORY AND WIND BIASED TRAJECTORY

TIME	K_A	K_θ	K_R	K_α
0	3.7	1	.454	0
10	3.5	1	.444	0
30	3.6	1	.436	0
50	2.7	1	.438	0
75	2.5	1	.443	0
90	2.7	1	.448	0
100	2.7	1	.448	0

GAIN SCHEDULE FOR ANGLE OF ATTACK FEEDBACK

TIME	K_A	K_θ	K_R	K_α
0	3.7	1	.454	0
3	—	–	—	2.1
10	3.5	1	.444	—
20	—	–	—	3
30	3.6	1	.436	3
45	—	–	—	2.1
50	2.7	1	.438	—
59	—	–	—	1.7
70	—	–	—	0.8
75	2.5	1	.443	—
90	2.7	1	.448	0
100	2.7	1	.448	0

K_I - 0.5, ALL TIMES

K_I = INTEGRAL GAIN

K_A = FORWARD LOOP PROPORTIONAL GAIN

K_R = RATE FEEDBACK GAIN

K_θ = ATTITUDE FEEDBACK GAIN

K_α = ANGLE OF ATTACK FEEDBACK GAIN

4.2.4.4 Results

Trajectory-Following Capability Versus Load Reduction. Figure 4.2.4-2 illustrates the basic tradeoff involved in selecting a control system for the SRB-X launch vehicle. On one hand, the ability to follow a trajectory that maximizes performance objectives versus the need to ensure that structural loading q-alpha remains below some design limit. The control system concept indicated as a "wind-knowledge" trajectory represents an idealized solution. The vehicle closely follows the trajectory with small structural loads as reflected in the q-alpha plot. However, assumption of advance knowledge of the exact wind profile is somewhat unrealistic. Without prior knowledge of the wind profile to be encountered, concept 1 employing an autopilot plus pitch program experiences a q-alpha of 4800. The addition of an angle-of-attack feedback loop, as defined by concept 3, reduces the q-alpha to 3700. The flightpath angle difference plot reflects the deviation of the actual vehicle flightpath from the commanded vehicle flightpath. One can see that the angle-of-attack feedback concept results in noticeable deviations during the early portion of the first-stage burn; however, at the end point, the vehicle has returned to the commanded trajectory. Consequently, because a reasonable q-alpha is achievable and the commanded end point can be reached, the angle-of-attack feedback loop is selected as the control concept for the SRB-X launch vehicle.

Thrust Vector Control System Assessment. The first-stage TVC gimbal rate and angle required to fly the desired trajectory are shown in figure 4.2.4-3. The specified limits for the existing STS SRB TVC system are ± 4.75 deg for gimbal angle and ± 3 deg/sec for gimbal rate. The no-wind-knowledge trajectory with autopilot only has gimbal requirements well within these capabilities. The spike in the gimbal angle and gimbal rate plots for the angle-of-attack feedback concept are due to the onset and removal of the assumed wind gust. A possible solution is the inclusion of some limits on angle-of-attack feedback. Further study is required on this problem but it should not present any insurmountable difficulties for the angle-of-attack feedback concept.

4.3 SYSTEM COMPARISON AND SELECTION

As previously indicated, a number of performance improvement options could be applied to the basic SRB-X concept. The primary purpose of the concept development effort was to identify which options were necessary to achieve a GEO payload capability of at least 15,000 lb. Performance estimates were based on the weight and propulsion characteristics described in section 4.2.

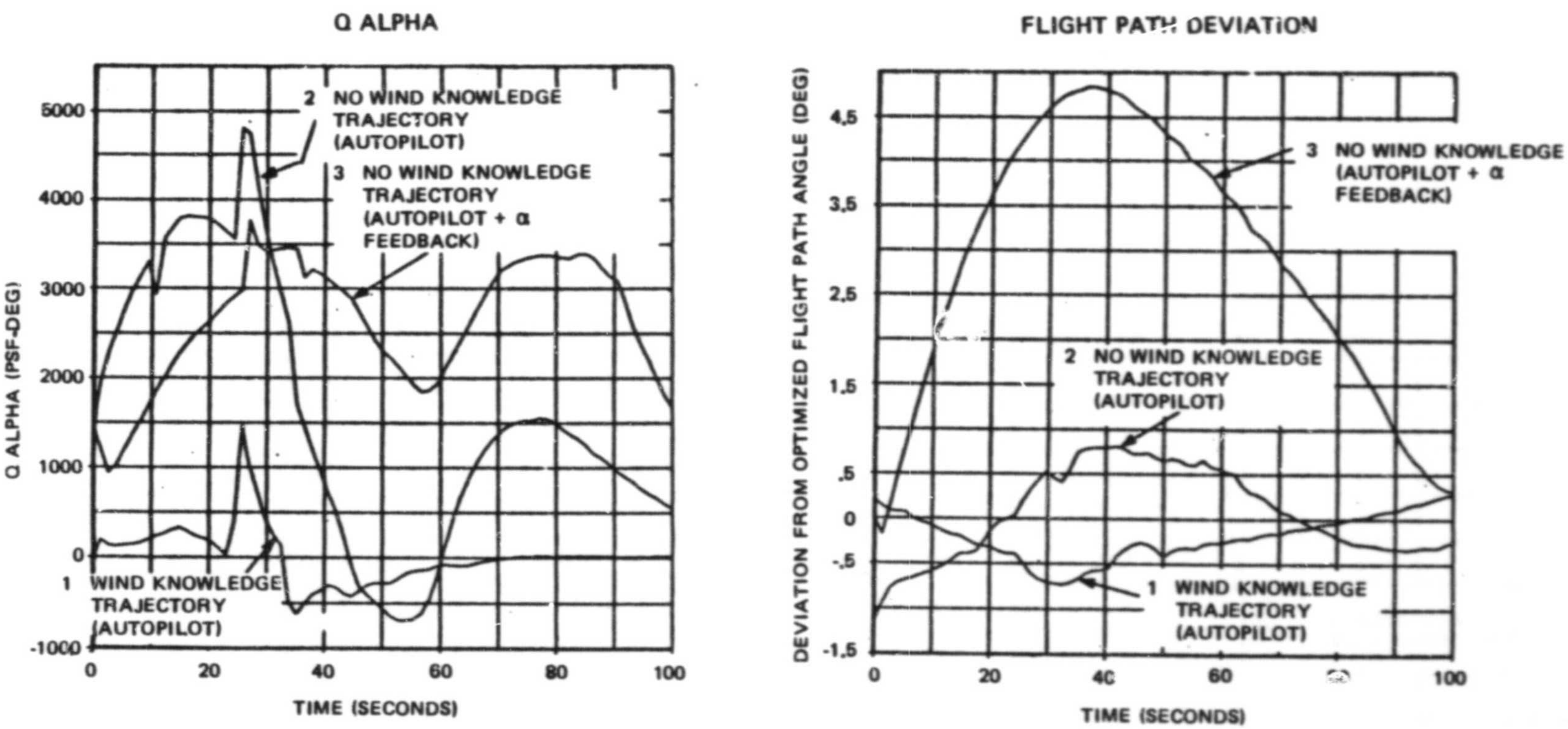


Figure 4.2.4-2. Trajectory-Following Capability and Loads

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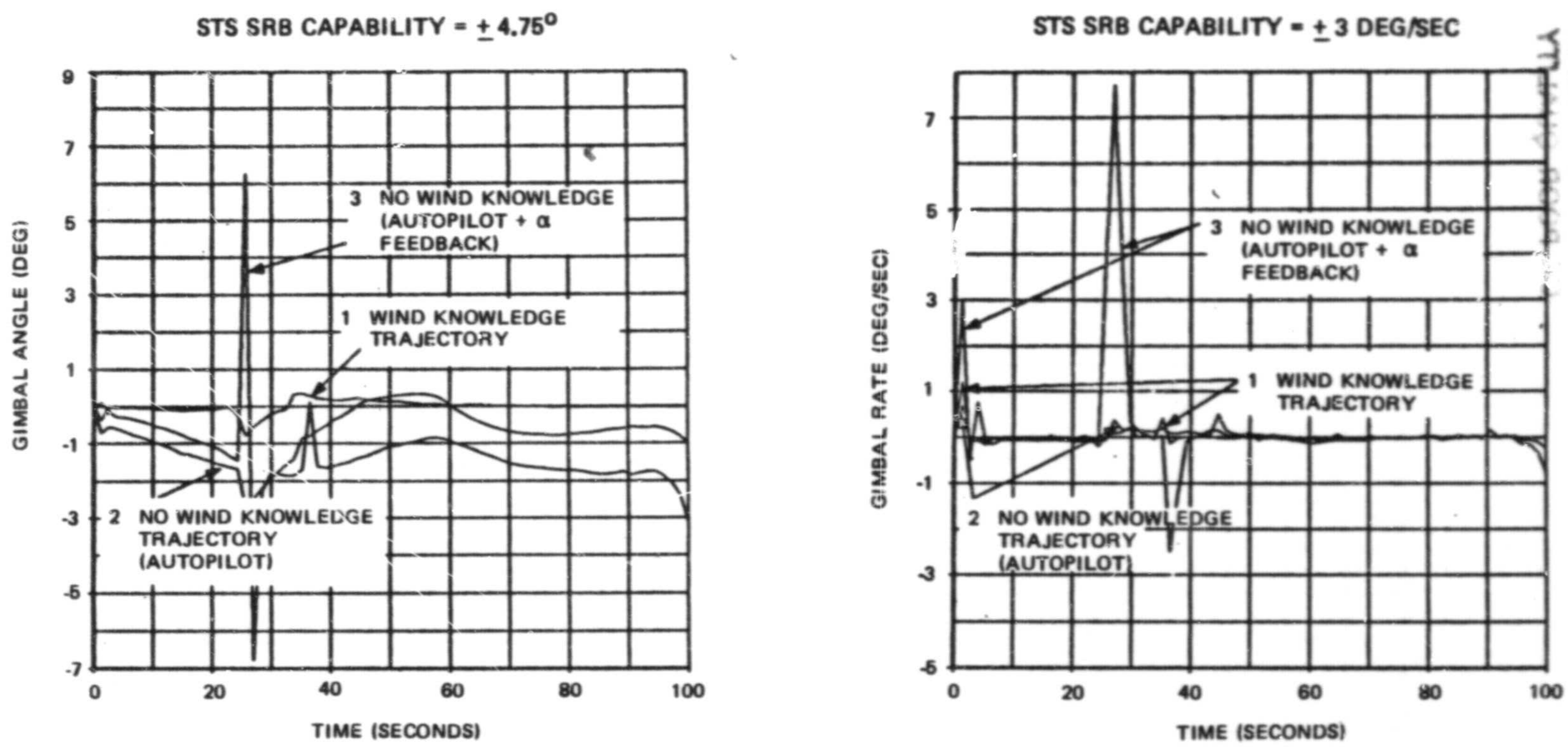
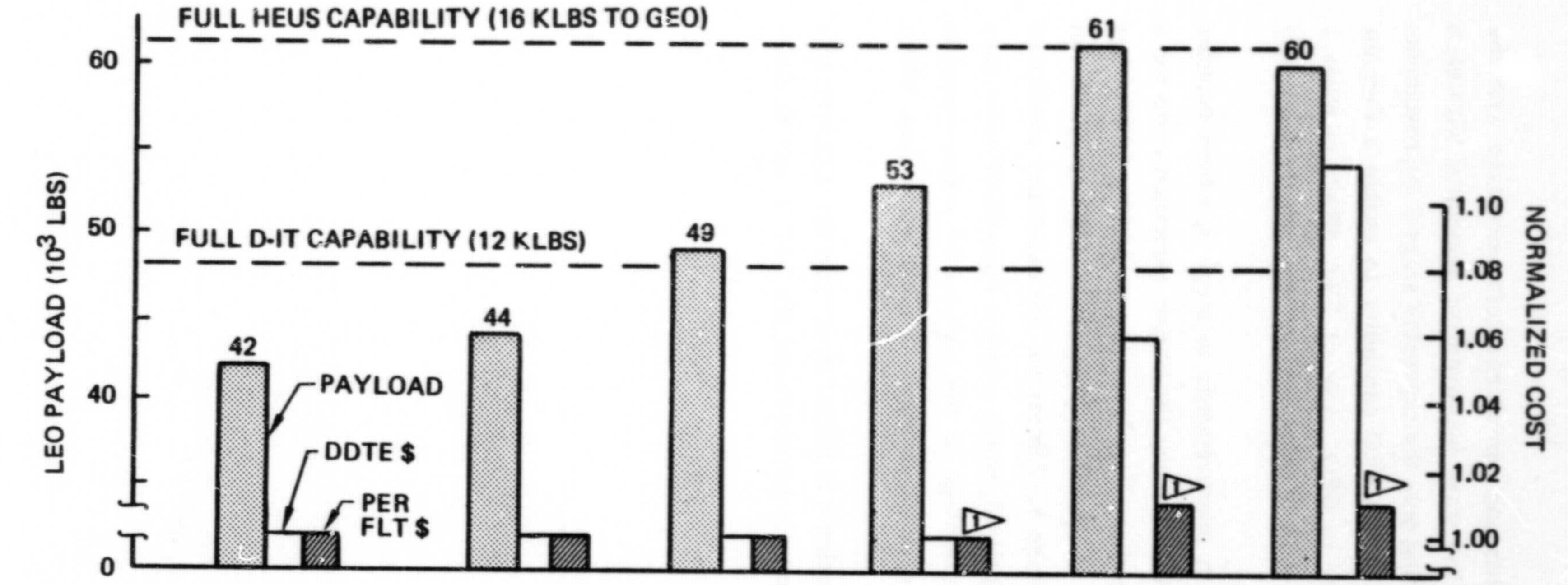


Figure 4.2.4-3. TVC Assessment

Comparison of the performance benefits and normalized cost associated with the improvements is presented in figure 4.3-1. The stage improvement associated with each vehicle option has been boxed in. Incorporating only the suggested stage 2 improvements (options 1 and 2) would provide more than enough LEO capability to enable a Centaur D-IT (stage 4) to deliver its full capability to GEO. Use of FWC SRM's in stage 1 increases the vehicle's LEO capability by 4000 lb compared to the vehicle with only stage 2 improvements.

The largest individual gain occurs with improvements to stage 3, which includes increasing the propellant loading by 50% and increasing the engine expansion ratio for a 3-sec gain in Isp. A vehicle incorporating these improvements, as well as the others indicated for option 4, allows delivery of a 16,000-lb payload to GEO if HEUS (an advanced cryogenic upper stage) is used as stage 4. Almost the full capability associated with HEUS would be possible using vehicle option 5, which employs high-MEOP steel case SRM's in the first stage. The primary disadvantage of the high-MEOP improvement is that due to the increased thrust, a flight dynamic pressure of 1300 psf occurs, which would have an impact on the structure.

Based on the foregoing data, vehicle option 4 is judged to contain the improvements that would best satisfy the assumed performance requirements for SRB-X and to do so with a minimum cost impact.



CONFIGURATION OPTIONS

STAGE	BASIC CONCEPT	1	2	3	4	5
1	(2) 4 SEG-SC	BASIC	BASIC	$\boxed{\text{FWC}}$	FWC	$\boxed{\text{SC-HI MEOP}}$
2	2 SEG-SC	$\boxed{\text{OPTIMIZ}}$	$\boxed{\text{FWC}}$	FWC	FWC	FWC
3	TITAN STG II	BASIC	BASIC	BASIC	$\boxed{\text{STRETCH}}$	STRETCH

1 2 REUSES OF STG 1

* RECOMMENDATION: OPTION 4

SC = STEEL CASE

FWC = FILAMENT WOUND CASE

Figure 4.3-1. Vehicle Comparison

5.0 RECOMMENDED VEHICLE DESCRIPTION

This section describes the recommended SRB-X vehicle that is the result of all prior analyses decribed in this document. Topics discussed include configuration charcteristics, flight operations, and performance capabilities.

5.1 CONFIGURATION CHARACTERISTICS

Characteristics of the selected vehicle, discussed in the following paragraphs, include configuration general arrangement, design features of each major element, and mass characteristics. The key subsystems for the selected vehicle are essentially the same as described in section 4.0.

5.1.1 General Arrangement

The general arrangement of the selected configuration for three- and four-stage vehicle applications is shown in figure 5.1.1-1. The first three stages are identical for both applications. Stage 1 SRB spacing is the same as for the shuttle because of constraints imposed by the launch mount at VAFB. The vehicle core (stages 2 and 3 and control module) relative to stage 1 is positioned as low as possible to minimize vehicle height. The limiting factor is the location of the kick ring for the forward struts so it does not interfere with access to the control module or reduce allowable payload diameter (see fig. 5.1.2-4 for additional detail). Stage 3 (Titan stage II) and the control module are enclosed within an interstage shell because they do not have sufficient strength to sustain bending loads occurring during flight. Payloads of 15-ft diameter and 60-ft length can be accommodated. This is accomplished at VAFB with a three-stage vehicle, employing a double taper nose cone and placing a portion of the payload within the nose cone. The four-stage vehicle reflects use of a standard Centaur D-IT as the upper stage and a 42-ft-long payload. The 219-ft height is accommodated at KSC through use of a new crane at the pad, which also allows removal of the payload and the fourth stage, should the need exist, rather than transporting the entire vehicle back to the vehicle assembly building (VAB). As a result, a 60-ft payload is possible above the fourth stage. Use of HEUS would reduce vehicle height by approximately 10 ft.

5.1.2 Design Features

Stage 1 of the vehicle involves two reusable FWC SRB's, essentially the same as those for use by the shuttle. Characteristics of each SRB and modifications for the SRB-X are identified in figure 5.1.2-1. Each SRM has over 1,100,000 lb of propellant and

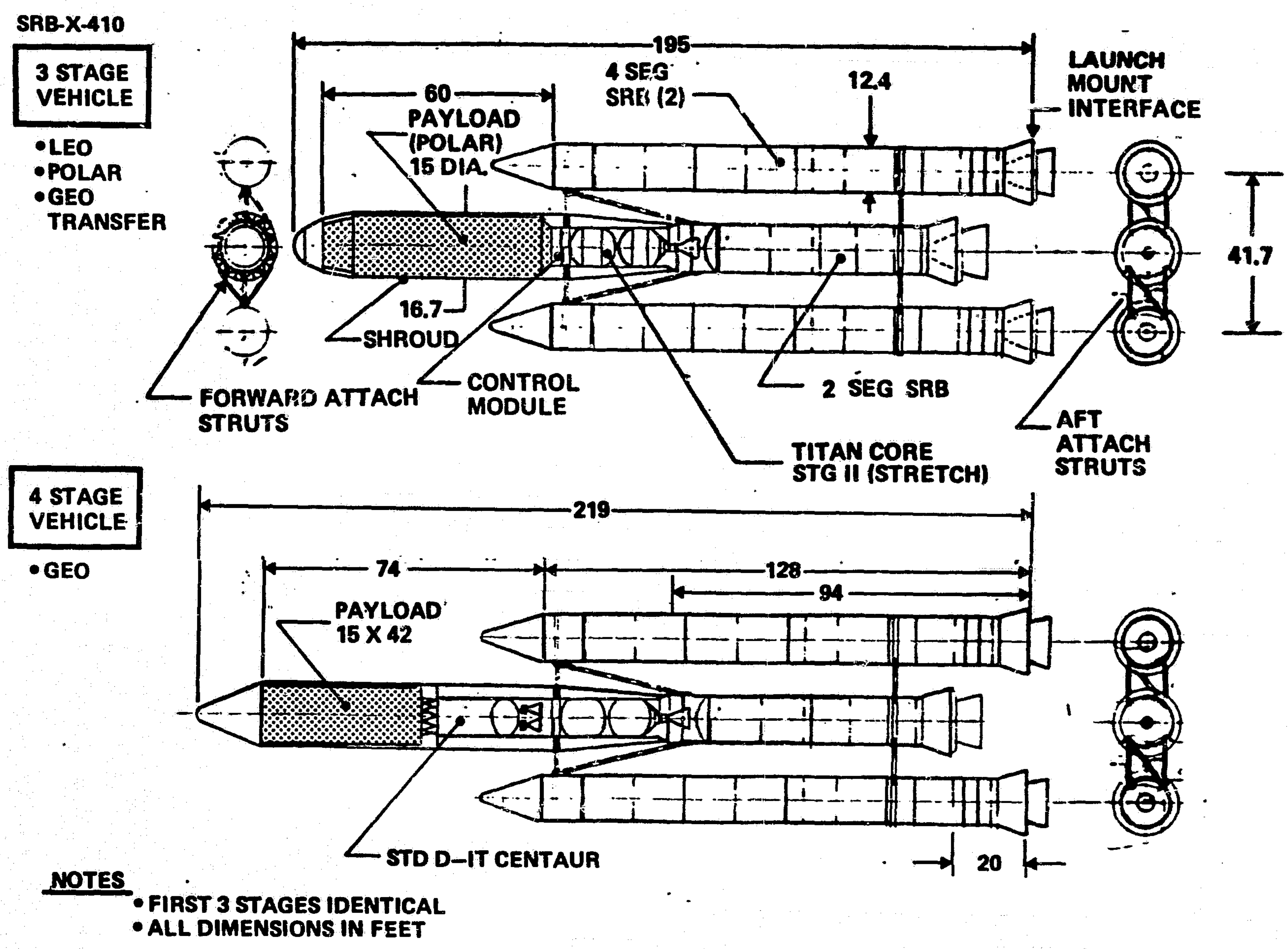


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Figure 5.1.1-1. Vehicle General Arrangement

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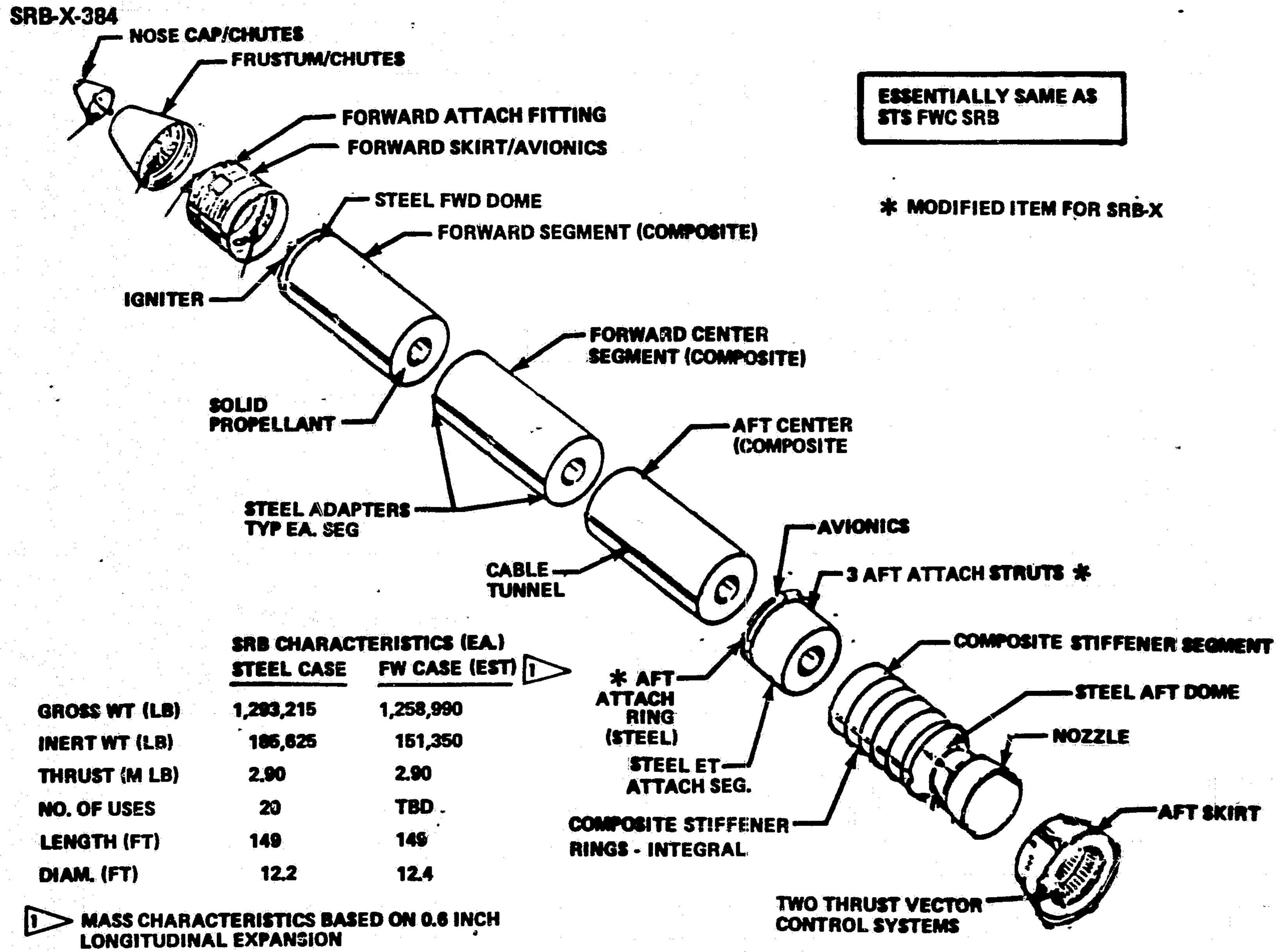

SRB CHARACTERISTICS (EA.)

	STEEL CASE	FW CASE (EST) [1]
GROSS WT (LB)	1,293,215	1,258,990
INERT WT (LB)	185,625	151,350
THRUST (M LB)	2.90	2.90
NO. OF USES	20	TBD
LENGTH (FT)	149	149
DIAM. (FT)	12.2	12.4

[1] MASS CHARACTERISTICS BASED ON 0.6 INCH LONGITUDINAL EXPANSION

Figure 5.1.2-1. Stage 1 Design Features

provides a thrust of 2,900,000 lb. The FWC SRM will continue to use steel components for the forward and aft domes and external tank attachment section. Cases associated with the four segments will use composite material; however, steel adapters are necessary at each end to allow segment attachments. Composite stiffener rings are used instead of steel rings on the aft segment. Modification to the attachment ring is due to the higher anticipated loads. Avionics and recovery provisions located in the forward skirt and frustrum are identical to those used on shuttle SRB's. Thrust vector control is provided by actuators and gimbaled nozzle of the SRM. Both systems are identical to those used by the shuttle SRB's.

The principal features of stage 2 are shown in figure 5.1.2-2. The stage is not recovered for reuse. The two-segment SRM consists of the forward and aft segments from the four-segment STS SRM. The ET attachment section is moved to the aft end of the aft segment, however, to enable proper alignment for the aft lateral struts between stages 1 and 2. The propellant load is approximately 605,000 lb and the thrust level is over 1,100,000 lb. For the desired acceleration profile and performance, a new grain design and nozzle are required with nozzle size being the largest possible with existing manufacturing facilities. A new aft skirt is incorporated to save approximately 8000 lb of inert weight. The forward skirt structure is similar to the existing shuttle SRB skirt although modifications are required to incorporate provisions for another thrust post to sustain loads from the forward drag struts and the associated kick ring. Pitch and yaw control during stage 2 burn is provided by gimbaling the SRM nozzle. Roll control during the second-stage burn is provided by thrusters in the forward skirt because those located on the control module are covered by the shroud for the first 65 sec of the stage 2 burn. The avionics system for stage 2 consists of a single integrated electronics assembly to accomplish all avionics functions presently provided on the STS SRB's, with the exception of recovery. In addition, multiplexer-demultiplexers are added to interface the stage 1 SRB's with the control module. Stage 2 avionics also include provisions for pyrotechnic initiators for stage 1 separation, stage 2/stage 3 separation, and stage 2 retromotors. A range safety system is also included and is cross-strapped to the range safety systems of the stage 1 SRB's (as is presently done on the ET and SRB's on the STS). Diametrically installed antennas and a power divider are also installed in the forward skirt of stage 2 to provide an RF link while the payload shroud covers the antennas installed on the control module. After the shroud is jettisoned, these antennas are switched out and the vehicle RF link is through the control module antennas.

Design characteristics of stage 3, control module, and interstage 2-3 are shown in figure 5.1.2-3. Stage 3 is a modified Titan core stage II using N_2O_4 and Aero-50

STAGE CHARACTERISTICS

- SRM
  - W_I = 60,190 LBS
  - W_p = 605,140 LBS
- SRB SUBSYS
  - W_I = 18,700 LBS
- THRUST (VAC AVG) = 1,130,000
- I_{SP} = 292.9 SEC
- BURN TIME = 156.6 SEC
- LENGTH = 987 IN. (INCL NOZZLE)
- DIAM = 149 IN.

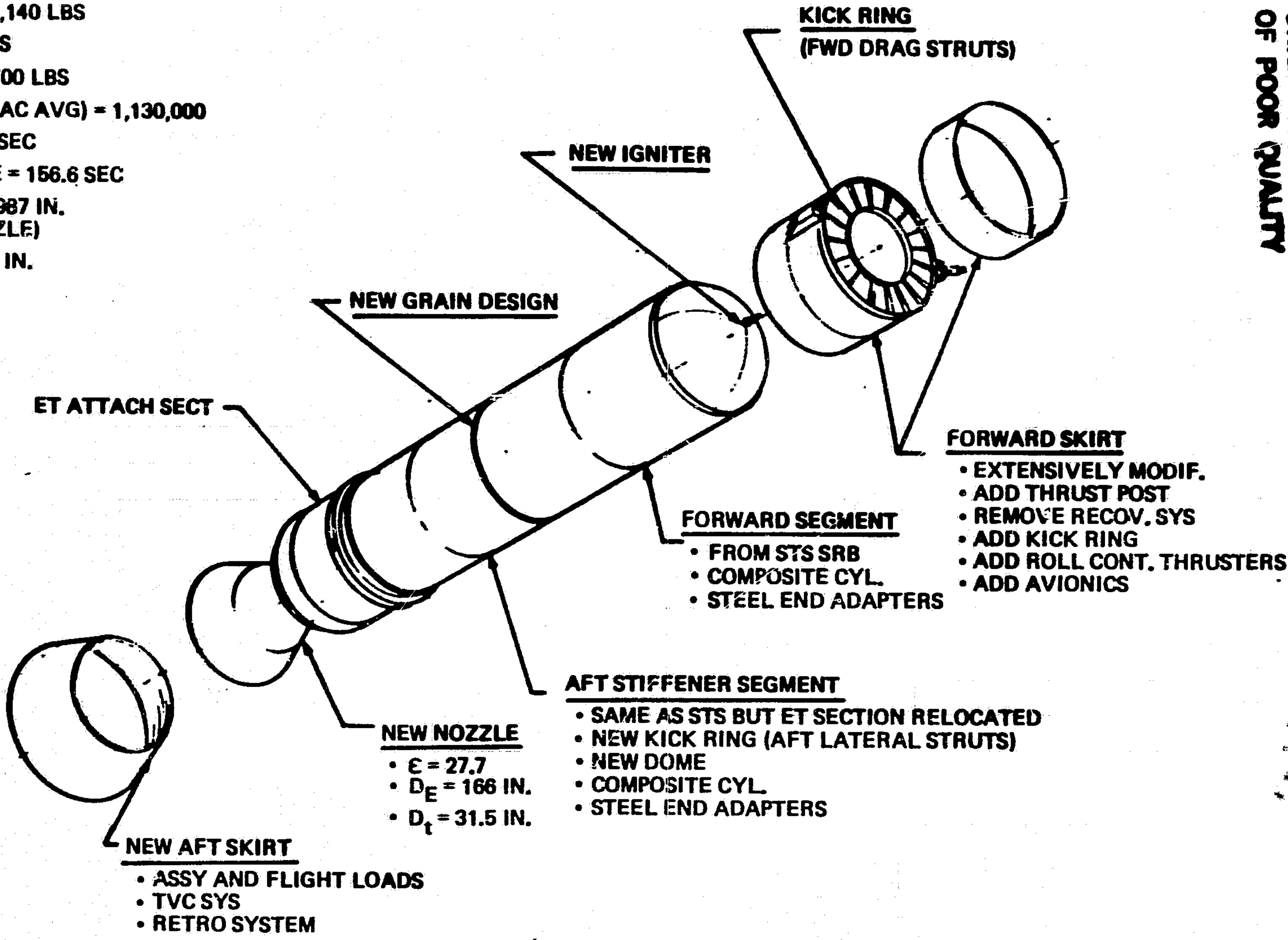

Figure 5.1.2-2. Stage 2 Design Features

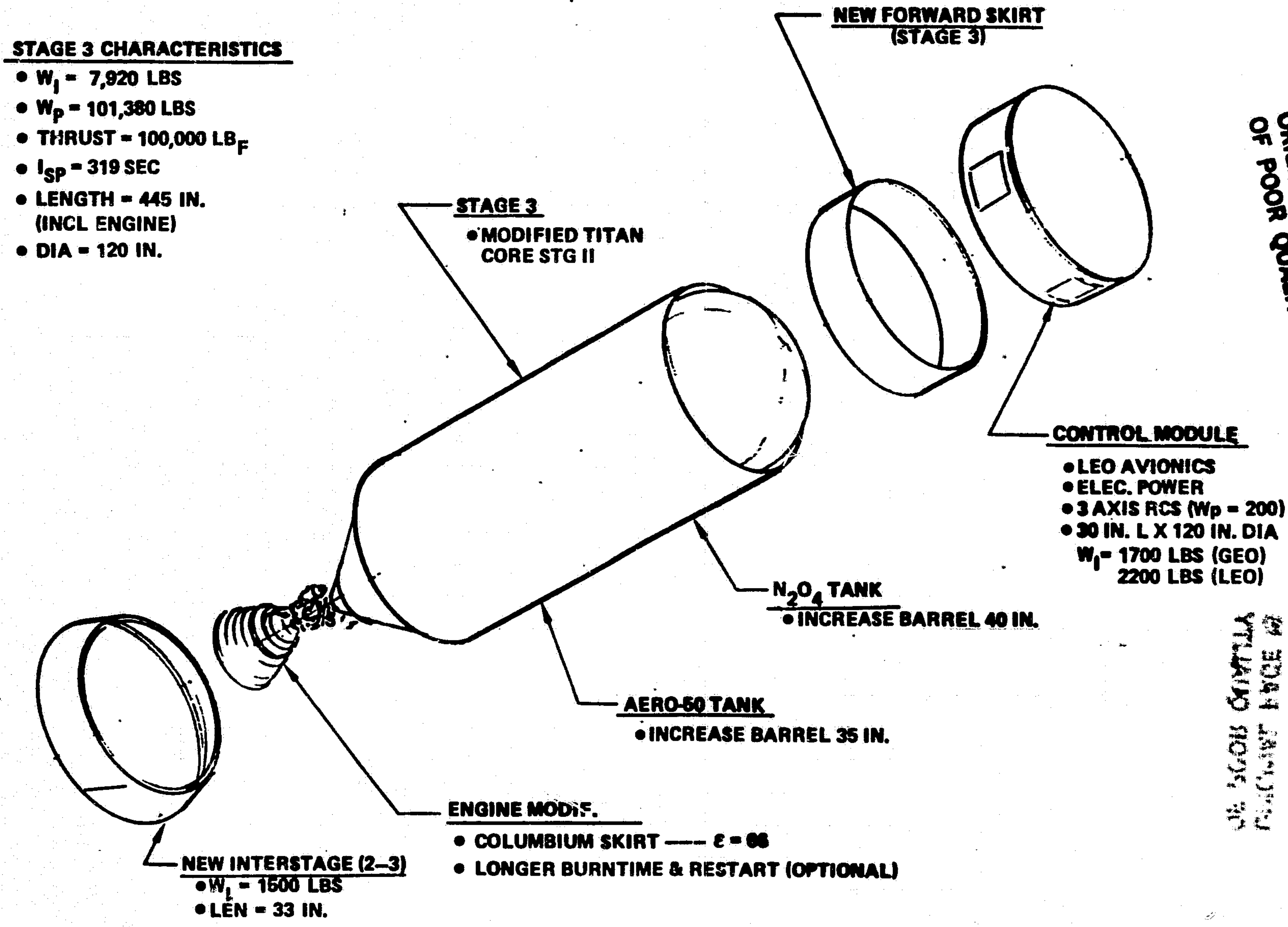

Figure 5.1.2-3. Stage 3 and Control Module Design Features

propellant. Principal modifications include increasing the propellant loading by 50% to a total of 101,000 lb and converting to a columbium engine skirt due to the longer burntime. The new engine skirt also has a larger expansion ratio giving a 3-sec improvement in specific impulse. Engine thrust level is 100,000 lb. The engine is gimbaled for pitch and yaw control, and exhaust from its gas generator is supplied to a separate thruster for roll control. The stage 3 avionics system includes the basic Titan second-stage complement of hardware, which in turn is connected into the vehicle data bus through MDM's. A range safety/inadvertent separation system is also installed. The control module is a separate unit whose primary function is to accommodate vehicle guidance and control avionics and three-axis reaction control system (RCS) for the terminal phase of the flight. The avionics complement is influenced by whether or not a smart (e.g., inertial upper stage (IUS), Centaur, HEUS) upper stage is involved in the flight. If not, all avionics necessary for vehicle communication, data management, flight control, instrumentation, and range safety are provided within the control module. However, if a smart upper stage is present, it provides computation and guidance capability for the flight to LEO. In this case, similar equipment in the control module is replaced with a redundant autopilot—a new element. Remaining equipment can be obtained directly or derived from IUS or the shuttle.

The vehicle element connecting stage 1 and the core is the interstage 1-2. Its configuration and characteristics are shown in figure 5.1.2-4. Major subelements include a forward strut system, shell section surrounding the third stage and control module, and an aft strut system. Stiffness criteria dictated by flight control considerations size all lateral struts. Liftoff loads size the drag struts. Because of the high loads transmitted through the struts, all use high-strength steel. In addition to sustaining the loads transmitted from the thrust of the first-stage SRB's, the shell also must be stiff enough to minimize shroud deflections.

Design features of the shroud are shown in figure 5.1.2-5. Major sections include the nose cone, payload section, and stage 4 section. The interstage 1-2 shell and forward ring assembly are also shown because of their strong interaction in sizing the shroud elements. The shroud was sized to accommodate a 15-ft-diameter payload with length sufficient for a standard Centaur D-IT plus 42-ft-long payload. Thermal considerations dictated design features of the nose cone. A Q-alpha value of 5000 psf-deg was used to size the cylindrical sections; however, the payload section still resulted in minimum gage. The stage 4 section was designed by stiffness for the deflections expected at the forward bearing reaction (FBR). The FBR, in turn, minimizes relative deflection between payload

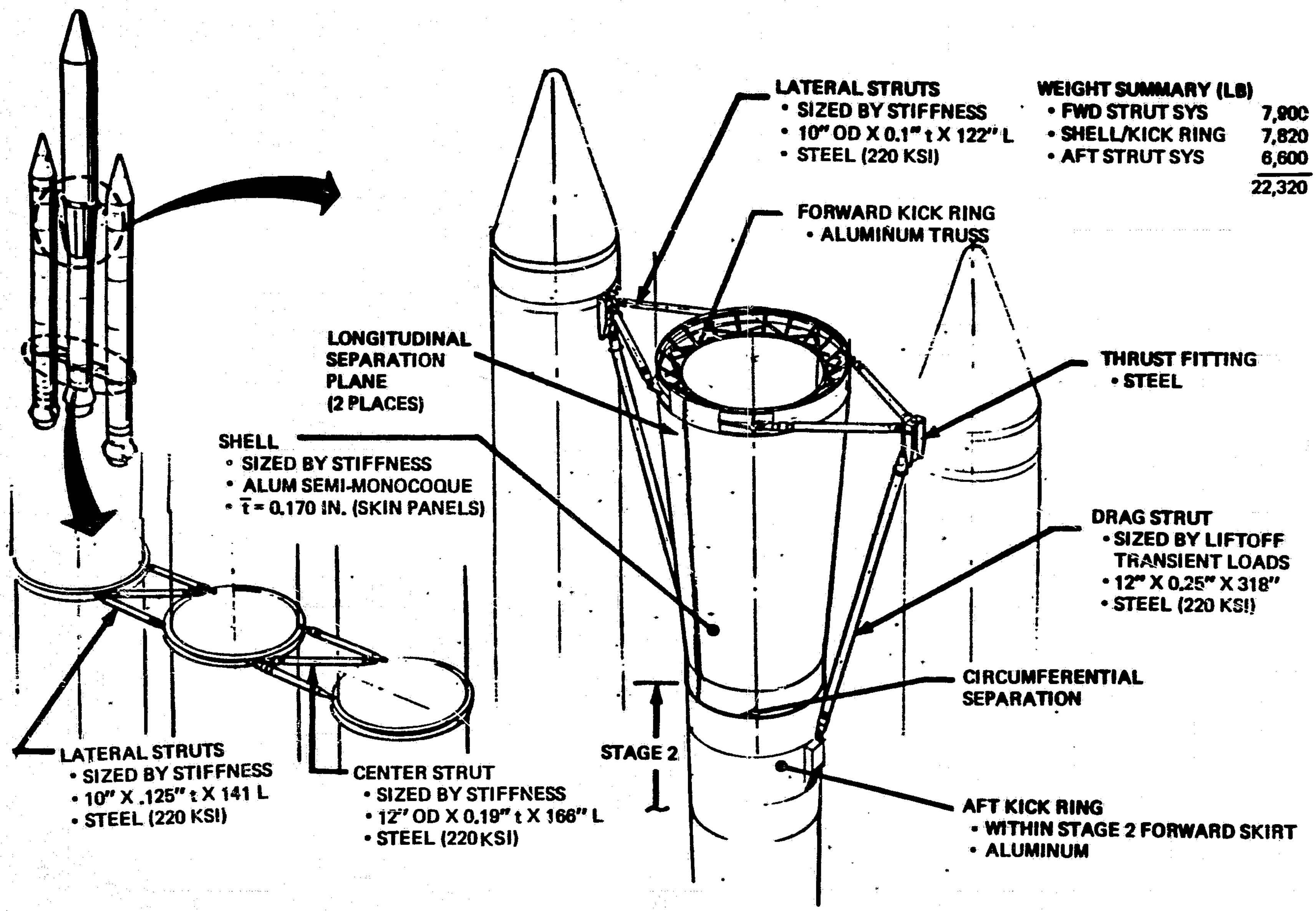

Figure 5.1.2-4. Interstage 1-2 Design Features

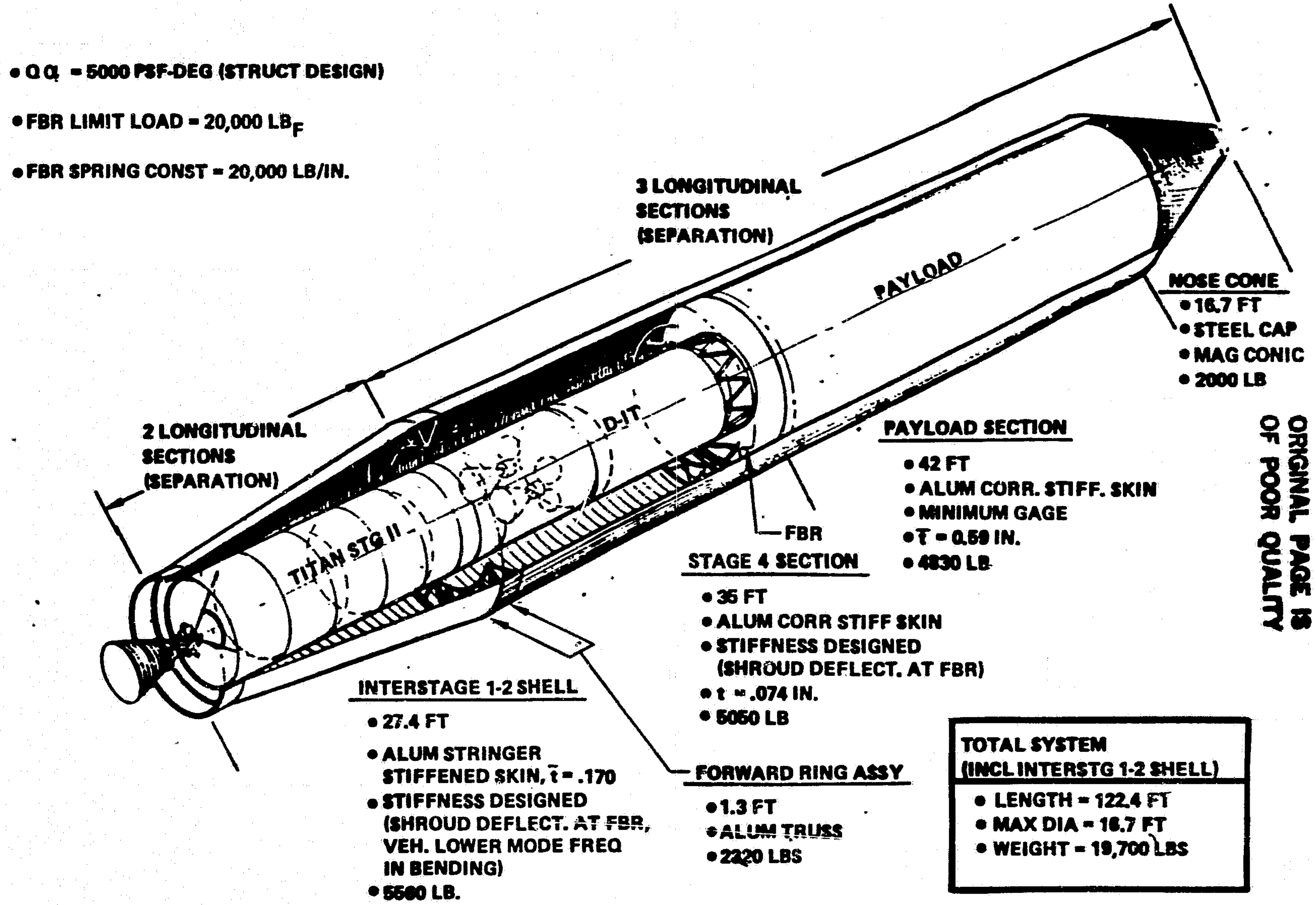

Figure 5.1.2-5. Shroud Design Features

and shroud. Separation, as well as shipment of the large shroud, resulted in a design with three longitudinal sections—each divided into lengths to cover a wide range of payloads.

5.1.3 Mass Summary

The gross liftoff weight (GLOW) for the vehicle is approximately 3,400,000 lb. A breakdown by system element for both LEO and GEO missions is presented in table 5.1.3-1. The key difference between the two missions is the amount of payload and whether a fourth stage is present. A point of interest regarding GLOW is that it is nearly 1,000,000 lb less than that of the shuttle for approximately the same net payload. A more detailed weight breakdown is presented in appendix B.

5.2 PERFORMANCE

Vehicle flight characteristics and payload capabilities are described in the following paragraphs.

5.2.1 Flight Characteristics

The overall mission profile for the flight of the SRB-X is shown in figure 5.2.1-1. Key trajectory characteristics are shown in figure 5.2.1-2.

Liftoff occurs at 1.6g and the maximum acceleration during stage 1 burn is 2.9g. The maximum dynamic pressure of 780 psf is higher than for the shuttle primarily because of lower liftoff weights. Staging velocity of first-stage SRB's is also higher (+1300) fps) than for the shuttle and results in water impact approximately 50 nmi further down range. No significant change in recovery operations is anticipated relative to those used for the shuttle. Separation of the shroud occurs when the dynamic pressure reaches 1 psf, and the interstage 1-2 shell separates approximately 5 sec later. Additional details concerning separation of stage 1, interstage 1-2, and shroud are presented in figure 5.2.1-3.

The stage 2 burn has a duration of 150 sec. Burnout results in a relative velocity of 15,700 fps and a maximum inflight acceleration of 3.6g. Water impact of stage 2 is estimated to be 1300 nmi down range from the launch site. Recovery of this stage was judged unfavorable because of (1) loss of payload that would result from the weight penalty associated with thermal protection and the recovery system and (2) the cost impact of the recovery provisions, longer recovery operations due to distance, and perhaps a different recovery ship. Stage 3 has a burn of approximately 320 sec. Payload injection into LEO occurs approximately 10 min after launch, with a burnout acceleration of 1.4g's.

Table 5.1.3-1. *Vehicle Mass Summary*

	MASS IN POUNDS	
	LEO	GEO
PAYLOAD	60,700	12,100
PAYLOAD ADAPTER RING	800	200
SHROUD AND FBR	9,510	12,380
STAGE 4 (D-IT)	—	35,100
INTERSTAGE 3 - 4	—	900
CONTROL MODULE	2,200	1,700
STAGE 3 (T2S)	109,300	109,300
INTERSTAGE 2 - 3	1,500	1,500
STAGE 2 (2 SEG SRB) [1]	684,030	684,030
INTERSTAGE 1 - 2	22,320	22,320
STAGE 1 (2 - 4 SEG SRB) [1]	2,517,880	2,517,880
GLOW (LBS)	3,408,240	3,397,410

[1] FWC SRM'S (LONGITUDINAL EXPANSION = 0.6"/4 SEGMENTS)

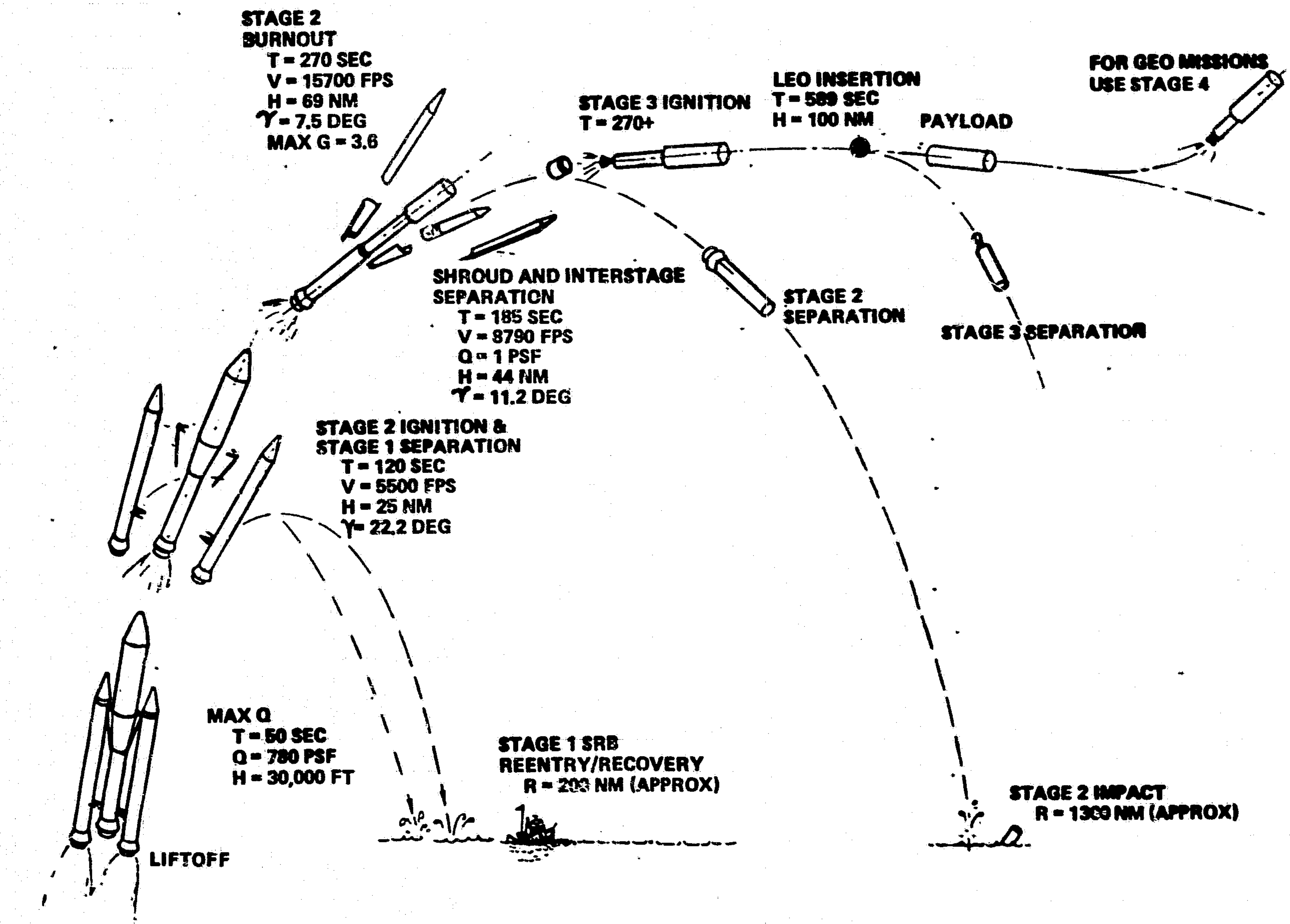

Figure 5.2.1-1. Mission Profile

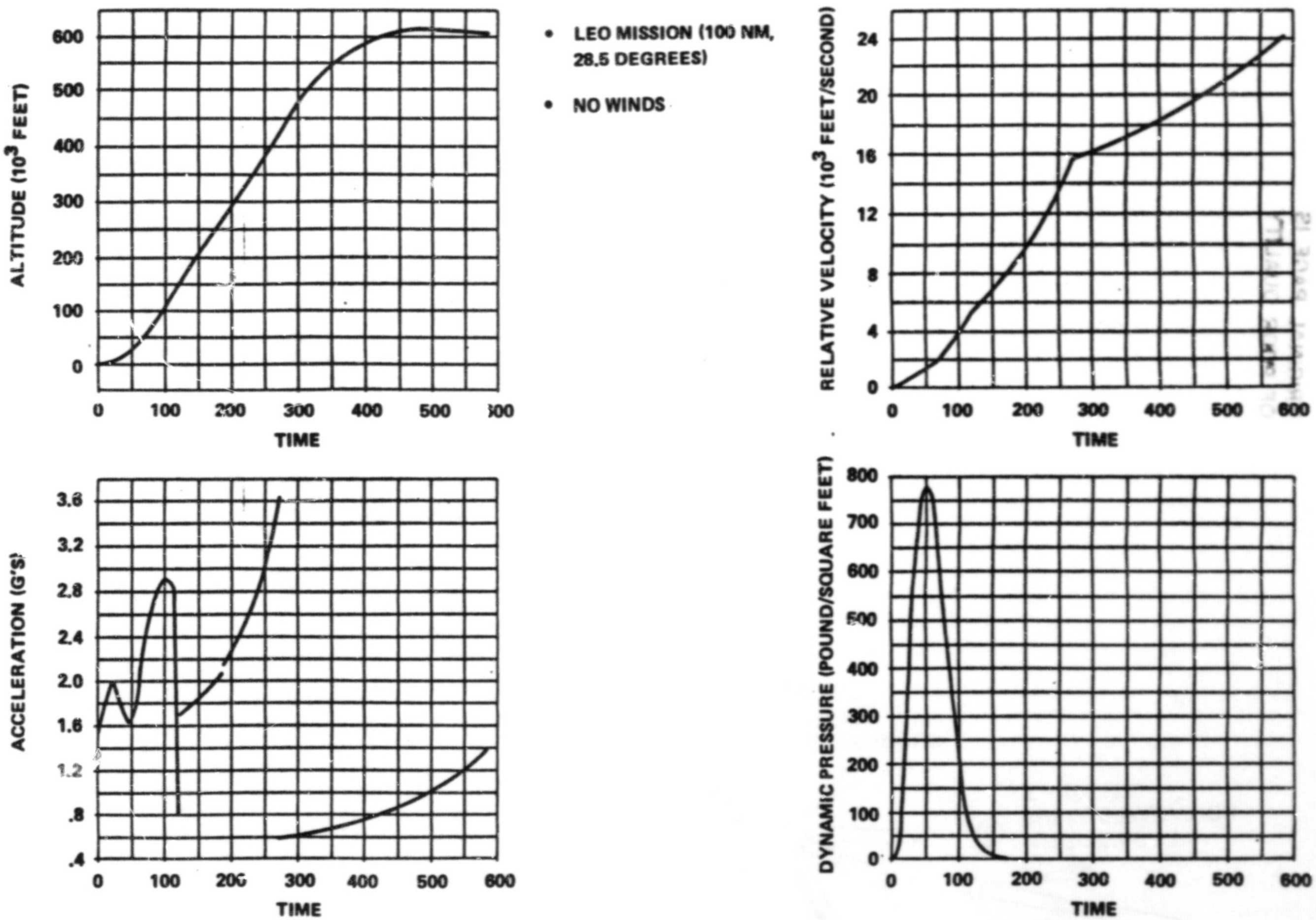

Figure 5.2.1-2. Nominal Trajectory Characteristics

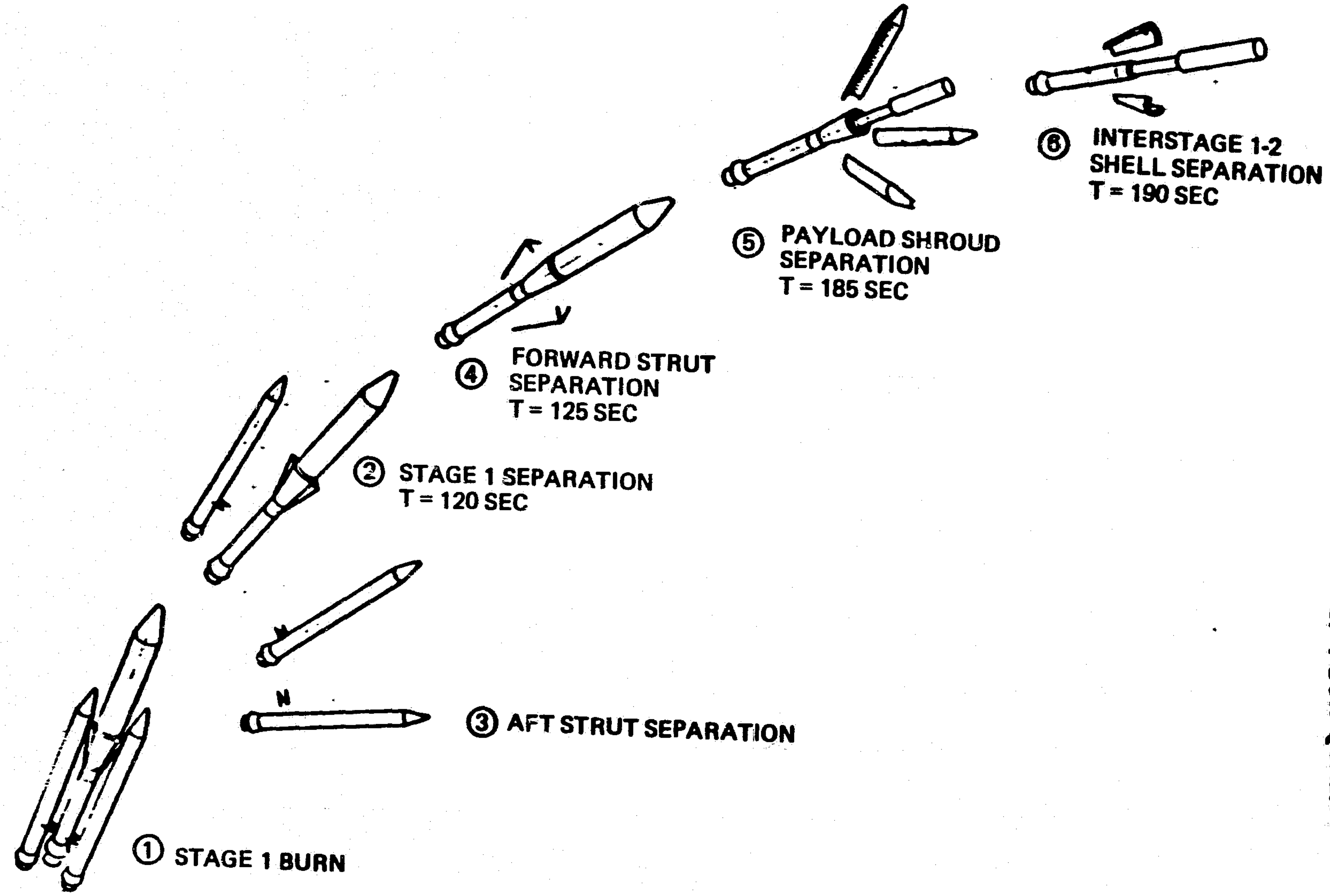

Figure 5.2.1-3. Shroud and Interstage 1-2 Separation

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5.2.2 Payload Capabilities

Performance of the selected vehicle is shown in figure 5.2.2-1 in terms of three- and four-stage capabilities. Weight and propulsion data supporting the performance estimate are presented in appendix B. Net payload capability is essentially the same as the specification values for the shuttle at low altitudes. Polar capability of 49,000 lb offers considerable growth beyond the current requirement of 32,000 lb. An attractive feature of the three-stage vehicle is that with restart of the third stage, 18,000 lb can be placed into GEO transfer which, with the appropriate insertion propulsion, should result in nearly 9000 lb of payload at GEO. Restart of the third stage could also be used to deliver over 4000 lb of payload directly into GEO, which is comparable to the T34D/IUS. The LEO capability of this vehicle allows as much as 16,000 lb to be placed into GEO with a shuttle-sized advanced cryogenic orbital transfer vehicle (OTV). The right-hand plot illustrates the significant payload advantage (nearly two to one) of the SRB-X relative to the shuttle in terms of missions involving high orbits or inclinations. The indicated performance does not include the impact of winds. Preliminary estimates of the impact of winds are included in a 1.7% reduction in LEO payload capability.

Additional performance capability is also seen as a possibility. The improvement resulting from changes in stage 1 and 2 is shown in table 5.2.2-1. Stage 2 improvements include changing from PBAN to HTPB propellant. This provides higher Isp, as well as greater propellant density, giving more propellant for the same inert weight From a vehicle-integration standpoint, the stage 2 nozzle can be increased to at least a 197-in diameter, for a higher expansion ratio and Isp. The composite material used in the SRM case could have a higher longitudinal expansion since this motor will not interface with the shuttle elements as do the stage 1 SRM's.

The stage 1 change viewed as most promising is that of increasing the SRM MEOP to obtain higher thrust and less gravity loss. A MEOP value that results in a dynamic pressure of approximately 1000 psf appears reasonable from a structural impact. Use of a shingle-top extendable exit cone (EEC) provides a good performance gain; however, it does involve considerable complexity relative to the other proposed changes.

In summary, the improvements suggested for stage 1 and 2 could provide a potential increase of 7000 lb (11%) to LEO with a development cost impact of approximately $80 million (12%).

- **3 STAGE VEHICLE (NET)**

•LEO (100 NM/28.5°)	60,700
•POLAR (100 NM/90°)	49,000
•GEO TRANSFER	18,100
•GEO INJECTION	4,200

- **4 STAGE VEHICLE**
  - •GEO INJECTION

•EXISTING STG (D-IT)	12,000
•ADV. CRYO (HEUS)	16,000

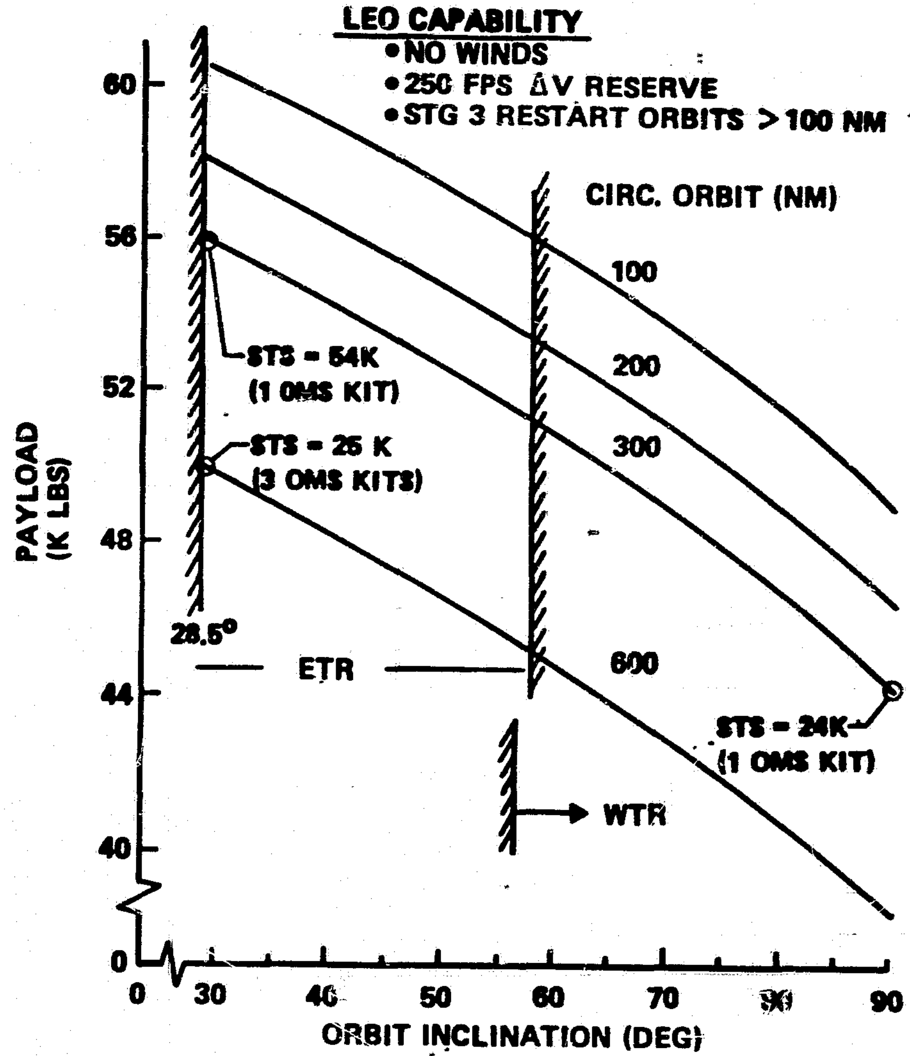

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Figure 5.2.2-1. Performance Capabilities

Table 5.2.2-1. Potential Performance Improvements

• CHANGES RELATIVE TO RECOMMENDED VEHICLE

IMPROVEMENT	GAIN (LBS)	IMPACT
• STAGE 2		
✓• PROPELLANT TYPE—HTPB I_{SP} = +3 SEC W_P = +35000	2400	LONGER CURE TIME ΔDDTE
✓• NOZZLE EXIT DIAMETER D_E = 166 TO 197; ε = 27 TO 39.5 I_{SP} = +5 SEC	1800	LARGER MANUF. FACIL (+$10M)
✓• CASE AXIAL GROWTH 0.6"/4 SEG TO 3"/4 SEG W_I = -4300	1000	Δ DDTE ($20M)
• STAGE 1		
✓• REDUCE SAFETY FACTOR TO 1.25 MEOP FROM 1016 TO 1080	2000	Δ DDTE ($35M) Q = 1000 PSF
• SHINGLE LAP EEC ε FROM 7.7 TO 11.3 I_{SP} = +14 SEC	3000	COMPLEXITY Δ UNIT COST Δ DDTE (<$5M)

✓ STRONG CANDIDATES——+7000 LBS ——— $80M

6.0 LAUNCH SITE OPERATIONS AND FACILITIES

This section describes the major ground operations and facility requirements that occur with launch of the selected SRB-X vehicle from KSC and VAFB. In summary, the operations and requirements at both sites are similar to those of the shuttle.

6.1 KSC LAUNCH SITE

6.1.1 Operations

Key features of KSC ground operations are shown in figure 6.1.1-1. Vehicle elements are processed using both NASA and Air Force facilities. Payloads will still be processed in the vehicle processing facility (VPF); however, they will be transported to the launch vehicle within the payload shroud rather than the payload canister. This approach is used because the RSS payload changeout room (PCR) cannot be used due to the location of the payload on the launch vehicle. The major steps involved in the payload processing are shown in figure 6.1.1-2. All vehicle elements, including payloads, are brought to the VAB for final assembly. Following assembly, the vehicle is transported to the pad for final servicing. Contingency payload access is provided at the pad, as well as payload removal provisions, if needed, rather than returning the vehicle to the VAB for payload removal.

Mainline ground operations time for SRB-X was found to be 800 hr, or approximately 5% less than required for the shuttle. A summary of the work hours required at each major facility is shown in table 6.1.1-1. VAB time for SRB-X is greater due to additional stacking of the stage 2 SRB and payload installation. Less time is required on the pad because there is no orbiter or payload installation. In offline operations, more SRB-X effort is required in the SRB processing and storage facility (PSF), again because of processing two additional segments for stage 2.

The launch preparation timeline is presented in figure 6.1.1-3. Vehicle configuration at key points in the assembly is shown in figure 6.1.1-4. Stage 1 stacking, alignment, and system tunnel activities are the same as for the shuttle. Closeout operations include cable verification, tunnel cover installation, and insulation work. Because closeout operations tend to relate to the SRB system tunnels, which are on the outboard side, assembly of the vehicle core (stages 2, 3, 4 and control module) can be done in parallel. Interstage 1-2 closeout is similar to shuttle SRB/ET closeout operations and involves the electrical systems, ordnance, and insulation application. The time allocation for the integrated vehicle test is the same as for the shuttle. Servicing and countdown on the pad are less than for the shuttle, primarily because no manned orbiter is present.

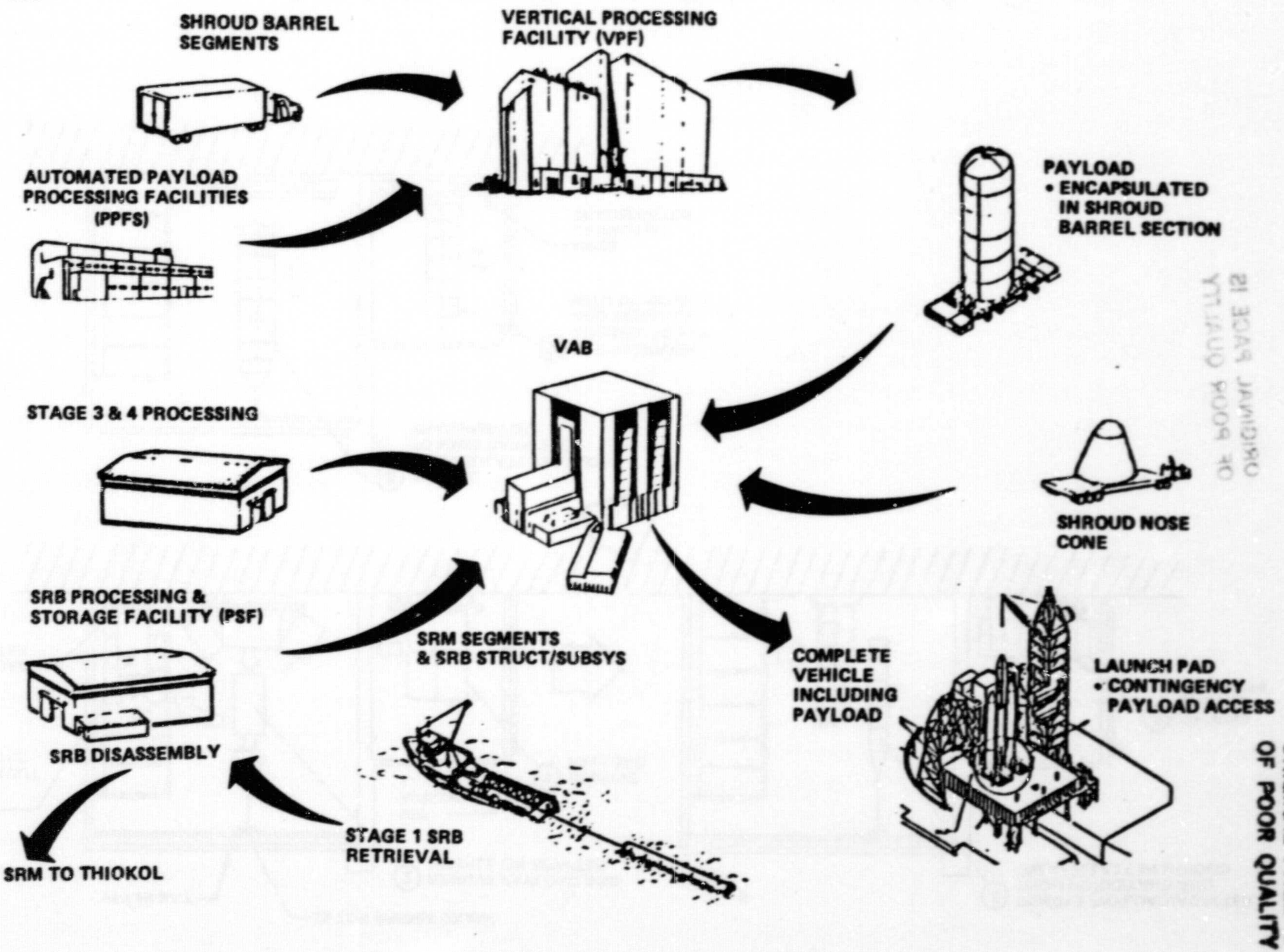

Figure 6.1.1-1. KSC Ground Operations

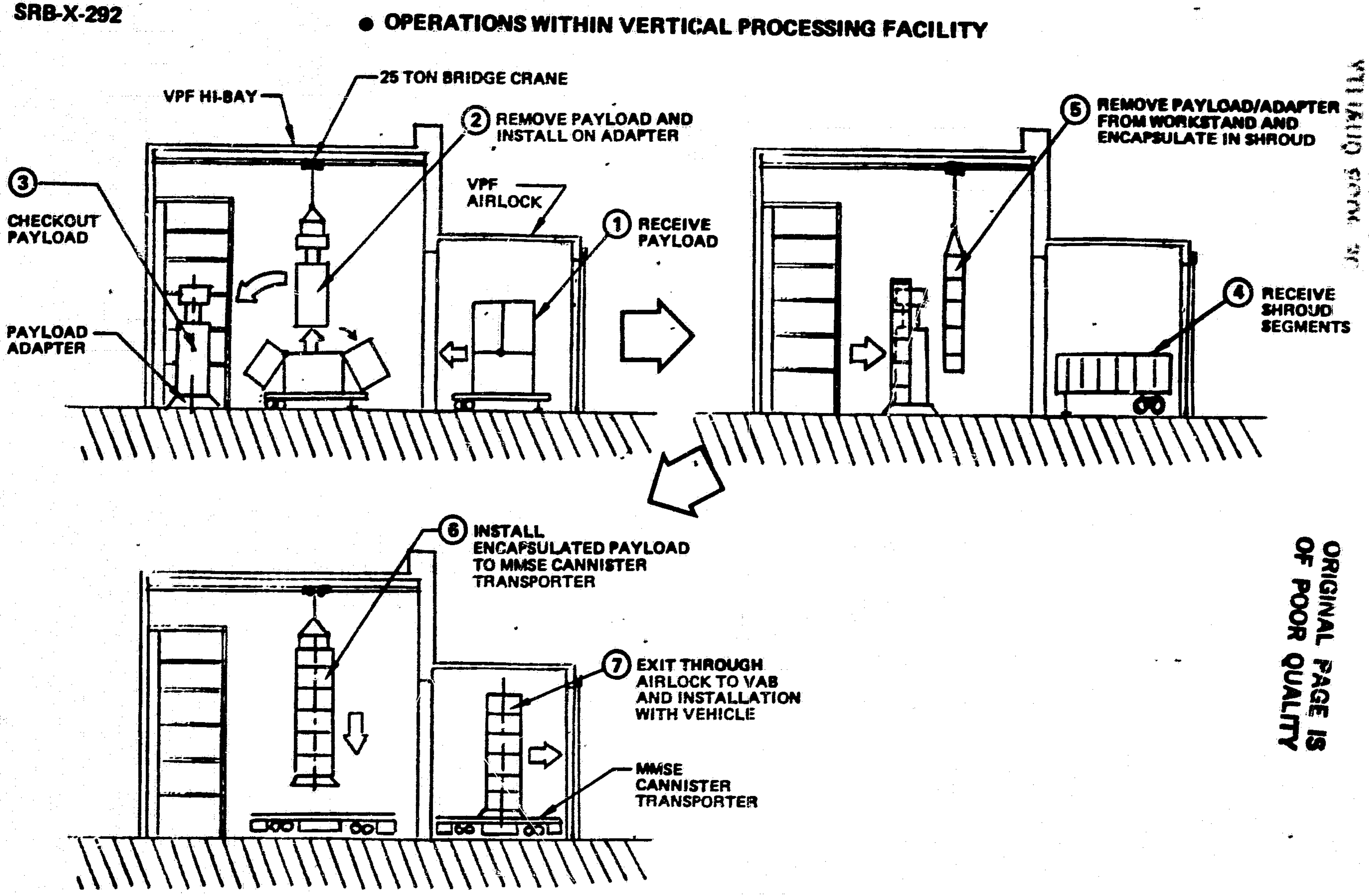

Figure 6.1.1-2. Payload Preparation, Checkout, and Encapsulation

Table 6.1.1-1. KSC Ground Operations Timeline Summary

- VERTICAL PAYLOAD INSTALLATION
- BASED ON STAR 22

MAIN LINE OPERATIONS (WORK HOURS)

FACILITY	STS	SRB-X	KEY DIFFERENCES
OPF	352	0	NO ORBITER
VAB	529 [1]	570	PAYLOAD/UPPER STAGE INSTALL 2ND STG STACKING
PAD	320	230	NO PAYLOAD INSTALL NO ORBITER SERVICING
TOTAL	840	800	

KEY OFF-LINE OPERATIONS (WORK HOURS)

SRB PSF	544	732	2ND STG SRM PROCESSING
SRB REFURB	160	160	RECOVERED SYSTEMS IDENTICAL
MLP REFURB	100	100	2ND STG PEDESTAL REMOVAL/INSTALL/ REFURB DONE IN PARALLEL WITH REG. REFURB AND NO ORBITER

[1] DONE IN PARALLEL WITH OPF OPS
DOES NOT INCLUDE AN ADDITIONAL 130 HRS FOR ET PROCESSING THAT IS DONE IN PARALLEL

SRB-X-373

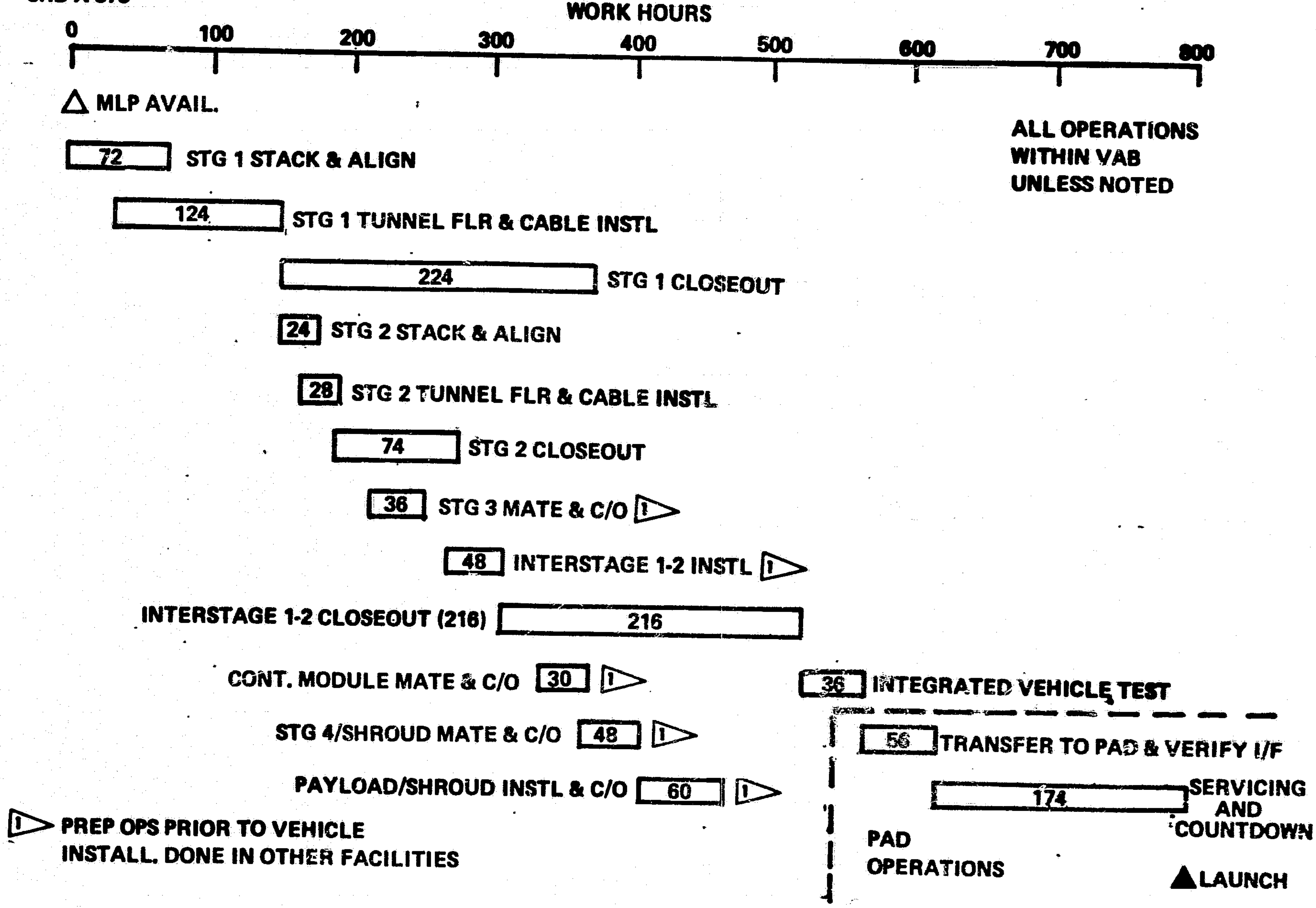

Figure 6.1.1-3. Vehicle Assembly and Launch Operations at KSC

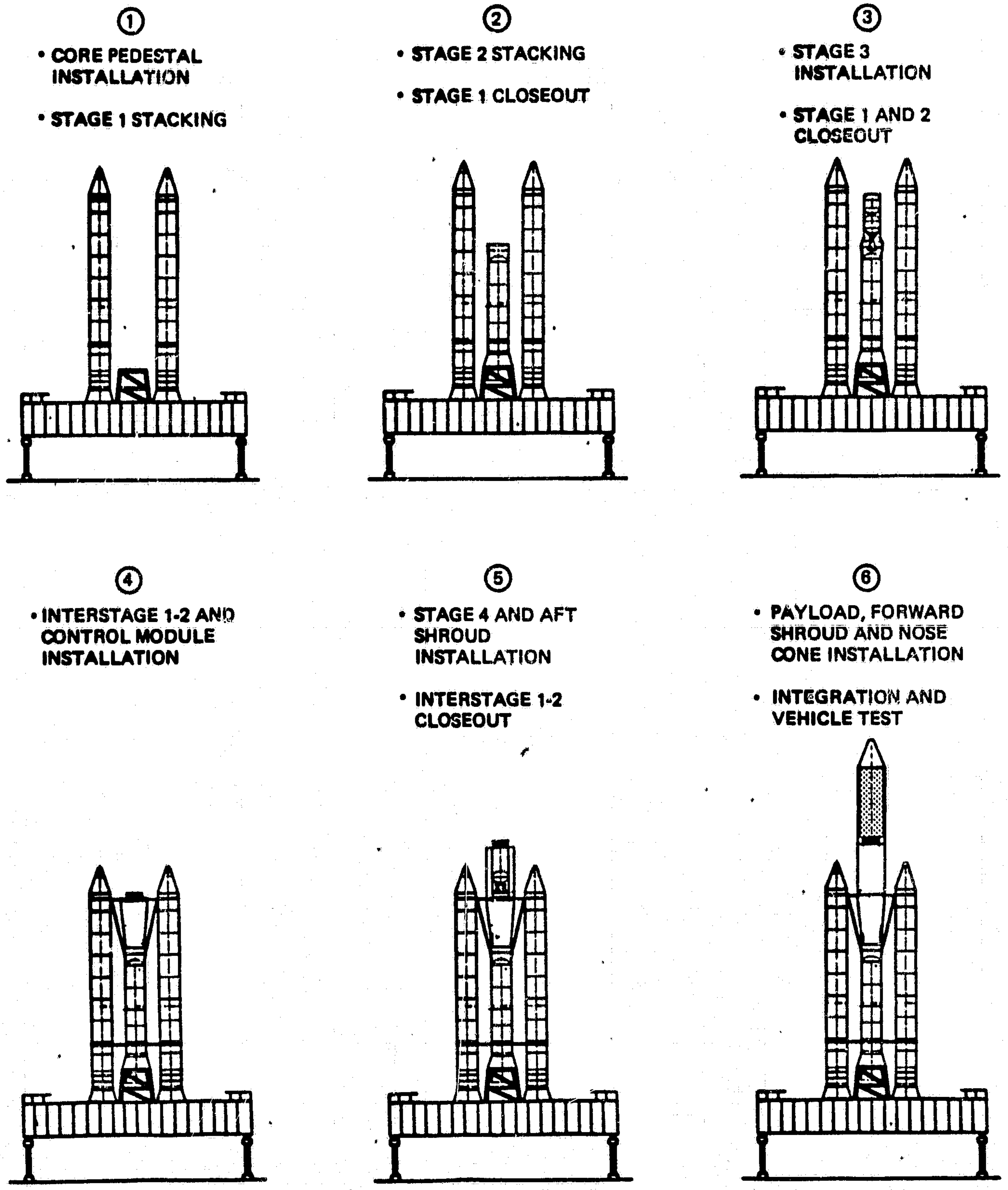

Figure 6.1.1-4. Vehicle Assembly Operations

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6.1.2 Facility Modifications

To perform required ground operations at KSC, some facility modifications are necessary, as indicated in figure 6.1.2-1. VAB modifications include assignment of highbay (HB)-4 for vehicle assembly. The shuttle would be assembled in HB-1 and HB-3 and the ET processed in HB-2. New access platforms are necessary for servicing and assembling the vehicle core. The crawlerway extension amounts to a spur track leading from HB-4 to the main roadway. Modifications at the pad involve both the fixed service structure (FSS) and rotating service structure (RSS) in terms of payload access and servicing (umbilicals) provisions needed for the vehicle and payload. Removal of the payload and solid upper stage (if present) requires a new 50t crane. Stacking of the core (stages 2 and 3) requires installation of a pedestal on the mobile launcher platform (MLP) and structural beefup beneath this area. Modification of the launch processing system (LPS) is necessary because of the new stages required relative to the shuttle. Additional provisions are also necessary at the SRB PSF due to two additional SRM segments associated with stage 2.

6.2 VAFB LAUNCH SITE

6.2.1 Operations

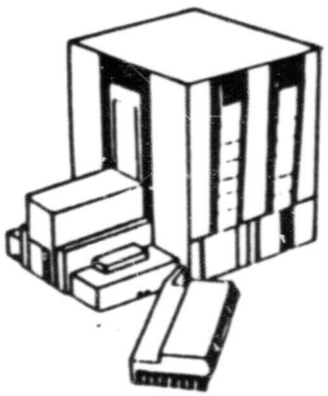
Ground operations at VAFB are illustrated in figure 6.2.1-1. Operations are similar to those used by the shuttle at SLC-6—the main difference being the method of transporting and installing payloads after processing within the payload preparation room (PPR). As at KSC, the RSS cannot be used to install payloads on the launch vehicle. Consequently, payloads will be encapsulated within their launch shrouds while in the PPR and will exit by way of the airlock rather than the payload changeout room. Key steps associated with payload preparation and encapsulation are shown in figure 6.2.1-2. Assembly of all elements occurs at the launch mount using equipment provided by the mobile service tower and shuttle assembly building. Installation of the payload is shown in figure 6.2.1-3. Both facilities are rolled back prior to launch.

6.2.2 Facility Modifications

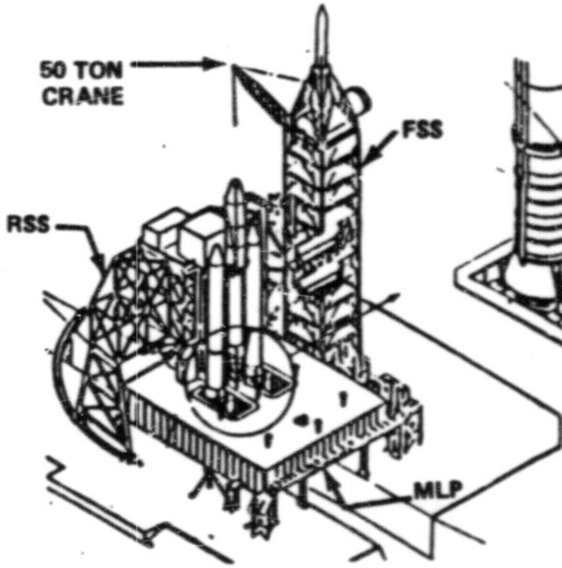
Necessary SLC-6 modifications are indicated in figure 6.2.2-1. MST modifications include installation of access platforms and servicing provisions, again for the core of the vehicle. The launch mount, serving the same role as the MLP at KSC, must be provided with pedestal and servicing provisions for the vehilce core involving stages 2 and 3; and payload servicing provisions must be incorporated in the access tower. SRB processing is the same as for the shuttle except for additional provisions for stage 2. The LPS must have additions to satisfy requirements for stages 2 and 3.

- ONLY ITEMS PECULIAR TO SRB-X ——NOT TO SUPPORT FLIGHT RATES GREATER THAN STS CAPABILITY

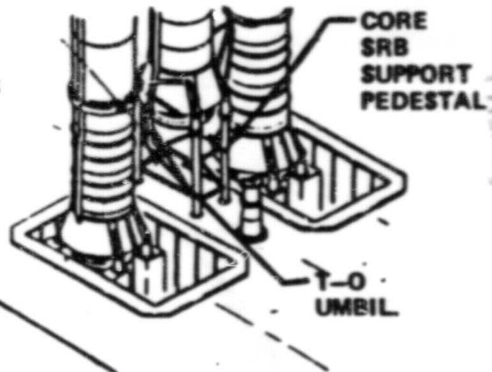
VAB



PAD 39B



MLP



- USE HB-4
- RELOCATE ET C/O CELL
- NEW ACCESS PLATFORMS
- CRAWLERWAY EXTENSION

LAUNCH PROCESSING SYSTEM (LPS)

- FOR STG 2, 3, 4 AT PAD AND FIRING RM

SRB PROCESSING & STORAGE FACIL (PSF)

- BUILD UP STANDS–STG 2
- STORAGE–STG 2

FIXED SERVICE STRUCT (FSS)

- REPLACE HHC WITH 50t CRANE
- BEEF UP FSS
- REWORK LIGHTING MAST
- ADD CRYO STAGE SERVICING AND T–O UMBILICAL
- ADD PAYLOAD SERVICING AND T–O UMBILICAL

ROTATING SERVICE STRUCT (RSS)

- ADD PAYLOAD ACCESS ARM
- ADD HYPERGOL UMBIL (STG 3)

MLP
(MODIFY-1, -2 OR -3)

- BEEF-UP COMPT 38
- T–O UMBILICAL
- PEDESTAL FOR CORE

OPTIONAL

- NEW MLP IF >21 FLTS/YR AT KSC

Figure 6.1.2-1. KSC Facility Modifications

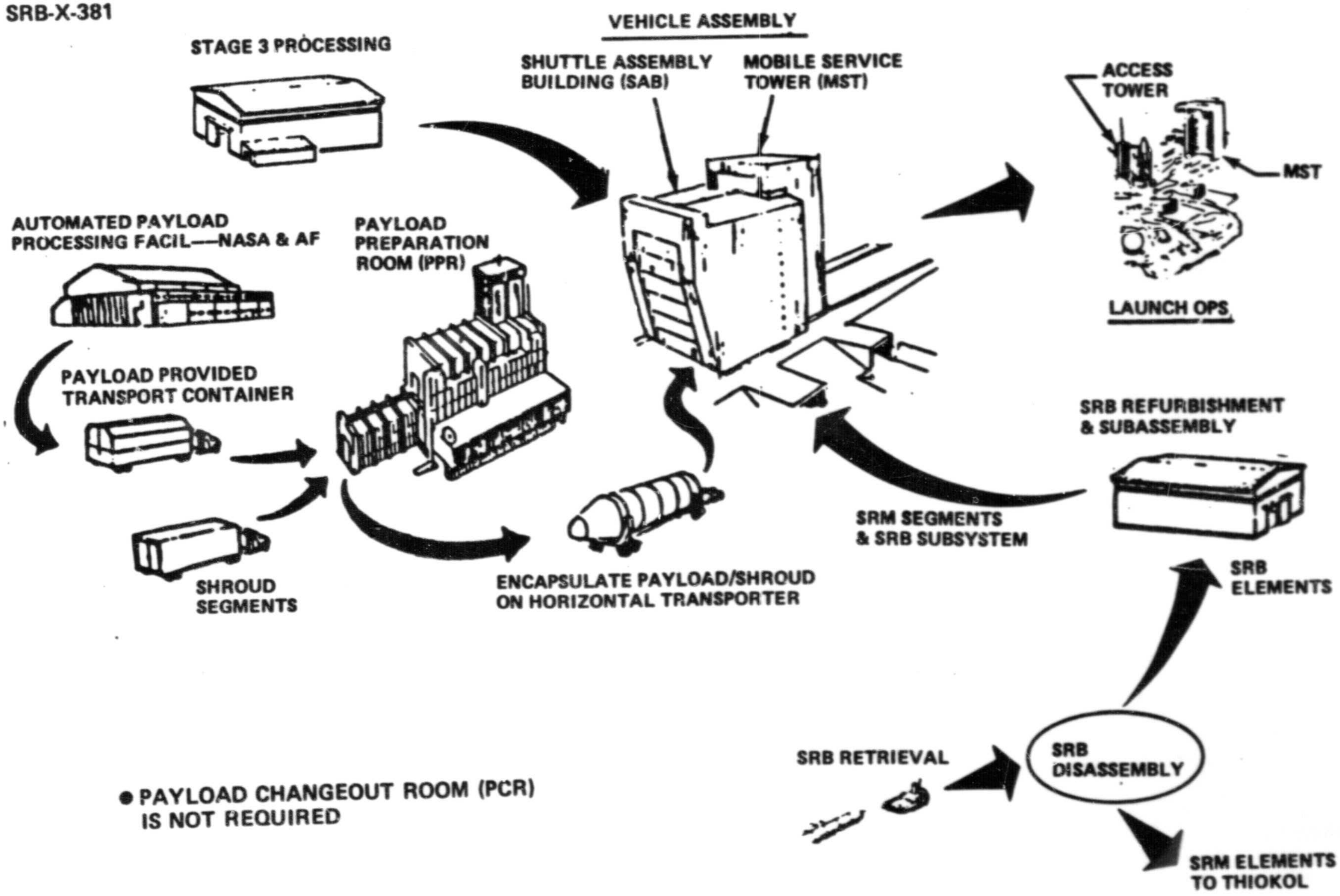


Figure 6.2 1-1. VAFB Ground Operations—SLC-6

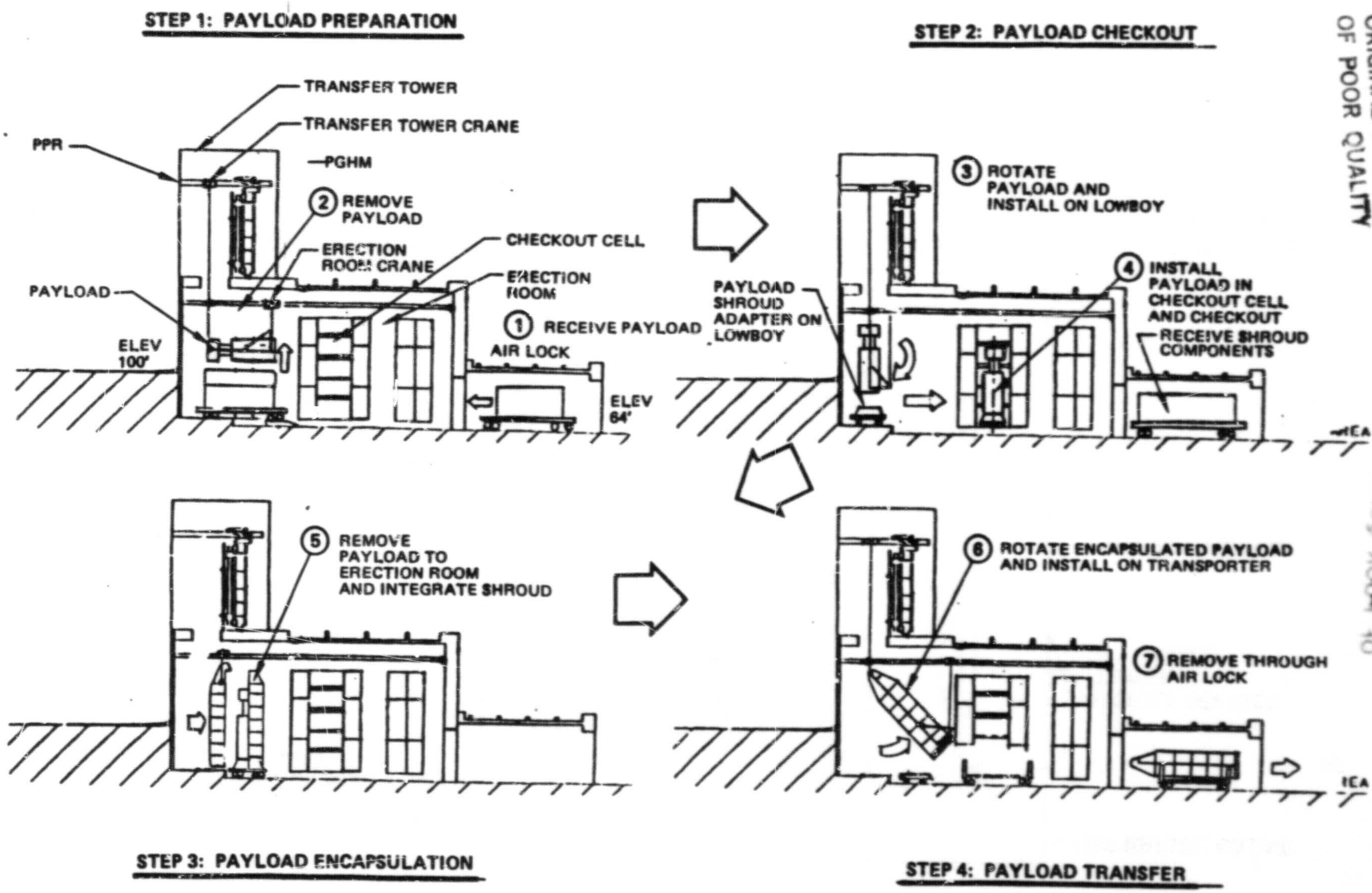


Figure 6.2.1-2. Payload Preparation and Encapsulation at VAFB

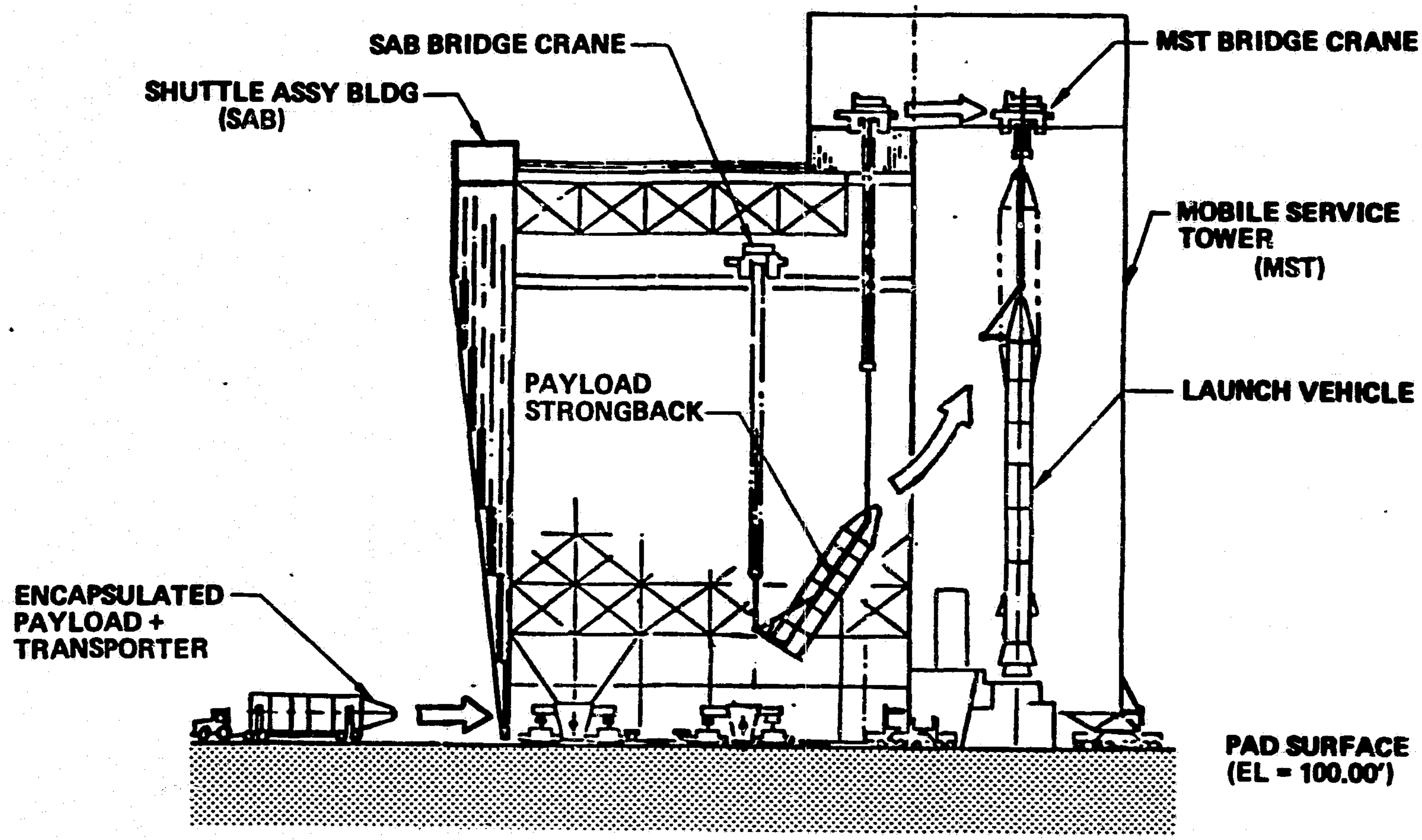


Figure 6.2.1-3. Payload Installation at VAFB

- ONLY ITEMS PECULIAR TO SRB-X----NOT TO SUPPORT FLIGHT RATES GREATER THAN STS CAPABILITY

MST
- SRB ACCESS PLATFORMS
- PAYLOAD ACCESS PLATFORMS
- HYPERGOL SERVICING
  - STAGE 2
  - SRB'S

LAUNCH MOUNT
- CORE SUPPORT PEDESTAL
- T–O UMBILICAL

ACCESS TOWER (AT)
- PAYLOAD T–O UMBILICAL
- PAYLOAD SERVICES

LPS
- STAGE 2 AND 3

SRB REFURB AND SUBASSEMBLY FACILITY
- STAGE 2 BUILDUP STANDS AND STORAGE

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Figure 6.2.2-1. VAFB SLC-6 Modifications

7.0 IMPLEMENTATION PLAN

This section presents the plans and schedules associated with the implementation of the selected SRB-X vehicle.

7.1 OVERVIEW

First flight of the SRB-X is estimated to occur 4.5 years after authorization of phase C/D go-ahead. This schedule assumes no preimplementation effort and a conservative test program. Key activities associated with the development program are shown in figure 7.1-1. The vehicle design effort would be completed within the first 2 years, followed by approximately 2 years of qualification and major ground tests. Facility modifications at KSC and VAFB would be completed within 3.5 years.

7.2 TEST PROGRAM

A key element of the implementation plan is the test program that is required. The following paragraphs discuss the major tests at the system level and those suggested for the integrated vehicle.

The major tests associated with individual systems are summarized in table 7.2-1. Major qualification tests include five static firings of the stage 2 SRM, stage 3 engine qualification, system integration and qualification test for the control module, and separation test for interstage 1-2 and shroud.

Integrated vehicle tests are defined as those involving all major system elements of the vehicle. The tests and vehicle elements required for each test are summarized in table 7.2-2. Three major ground tests have been assumed: (1) a structural test to verify primary loadpaths, (2) a ground vibration test to verify the coupled dynamic math model of the integrated vehicle, and (3) facilities pathfinder to verify interfaces that occur between modified facilities, equipment, and a configuration that differs from that of the shuttle. Where possible, use would be made of shuttle test hardware existing at the time of SRB-X testing. This hardware is expected to include two four-segment steel case SRB's and three four-segment FWC SRM's. One four-segment FWC SRM will be divided to provide the two segments required by each stage 2 for the structural test article (STA) and ground vehicle test article (GVTA) tests. The other two four-segment FWC SRM's will be used for the first stage in the GVTA. The two steel case SRM's that have been used with shuttle pathfinder vehicles at KSC and VAFB are suggested for pathfinder application for SRB-X. No flight test has been assumed because of the extensive

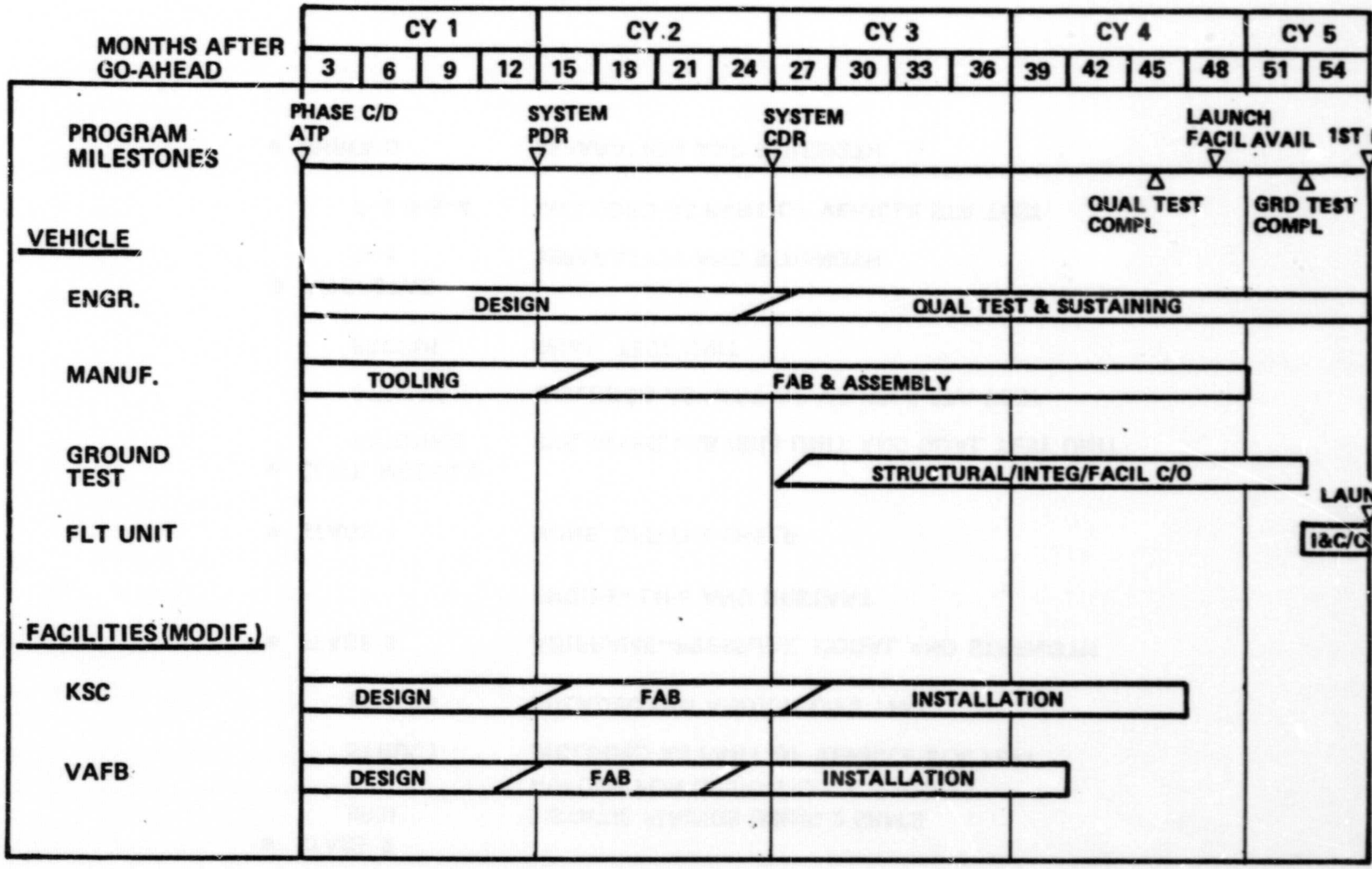

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Figure 7.1-1. SRB-X Program Summary Schedule

Table 7.2-1. *Major System-Level Test*

SRB-X-370

• STAGE 1		NONE, OFF-THE-SHELF
• STAGE 2		
	SRM	5 STATIC FIRINGS USING 2 SRM'S REFURB FOR OPERATIONAL FLIGHTS
	STRUCT	INCLUDED AS PART OF VEHICLE STA TEST
	SUBSYS	BREADBOARD AND/OR LIFE TEST
• STAGE 3		AIRFRAME—PRESSURE, MODAL AND STRENGTH
		ENGINE—LIFE AND RESTART
• STAGE 4		NONE, OFF-THE-SHELF
• CONT. MODULE		
	AVIONICS	SYS. INTEG.LAB (SIL) UNIT AND QUAL TEST UNIT
	STRUCT	INCLUDED AS PART OF VEHICLE STA TEST
	PROPUL	QUAL. TEST UNIT
• INTERSTAGE		
	1–2	SEPARATION AND STRENGTH
	2–3 & 3–4	INCLUDED AS PART OF VEHICLE STA TEST
• SHROUD		SEPARATION AND STRENGTH

Table 7.2-2. *Major Integrated Vehicle Level Test*

SRB-X-371

	STRUCTURAL TEST ARTICLE (STA)	GROUND VIBRATION TEST ARTICLE (GVTA)	FACILITIES PATHFINDER ARTICLE (FPA) [1]
● STAGE 1	HYD. JACK SIMUL.	STS FWC TEST UNITS	STS PATHFINDER SRB'S
● STAGE 2			
SRM	STS FWC TEST UNIT	STS FWC TEST UNIT WITH NEW ETA SECT.	QUAL MOTOR NO. 2
STRUCT	FWD & AFT SKIRTS	FWD AND AFT SKIRTS	FWD & AFT SKIRT
SUBSYS	NONE	MASS SIMUL	OPERATIONAL
● STAGE 3	STRUCT ONLY	STRUCT WITH MASS SIMUL OF SUBSYS	OPERATIONAL
● STAGE 4	NONE	MASS SIMUL	NONE
● CONT. MODULE	STRUCT ONLY	MASS SIMUL	OPERATIONAL
● INTERSTAGES	STRUCT ONLY	STRUCT ONLY	OPERATIONAL
● SHROUD	NONE, BY SUBCONT.	STG 4 SECT. ONLY	OPERATIONAL

[1] ALL SYSTEMS EXCEPT STG 1 TO BE REFURBED AS NECESSARY FOR OPERATIONAL FLIGHTS
NEED FOR FPA IS NOT FIRMLY ESTABLISHED

qualification and vehicle ground test program employed. In addition, many of the elements are modifications of existing systems.

7.3 DEVELOPMENT SCHEDULE

The schedule for each major element of the vehicle, vehicle level ground tests, and other key activities supporting the first launch is shown in figure 7.3-1. As indicated earlier, the first flight is scheduled 4.5 years after go-ahead.

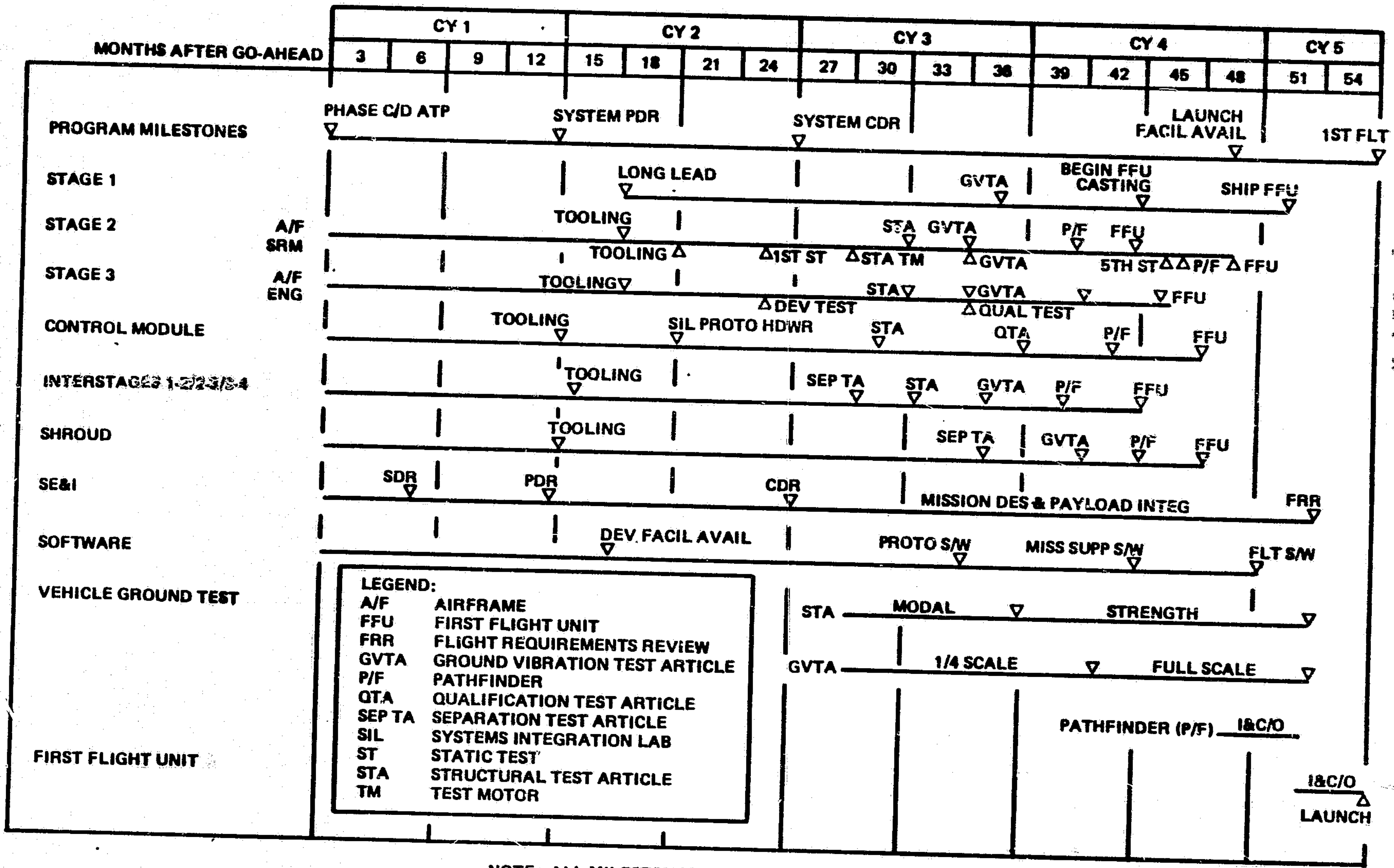
No development effort is required for stage 1; however, at least 33 months are required for long lead on the steel elements associated with the SRM's. The time period required to develop and deliver stage 2 is driven by the five SRM static firings judged necessary to verify performance and reliability. Further discussion regarding this SRM is provided at the end of this section. Although engine qualification contributes to the stage 3 duration, 30+ months are necessary for long-lead stage structural elements. The schedule for the control module primarily reflects the avionics suite with the duration being similar to that involved with the IUS avionics. Development time for the 16.7-ft-diameter shroud was based on extrapolations from schedules associated with 14-ft-diameter shrouds developed by Lockheed. Interstage 1-2, which involves a combination of strut systems and a shell that separates, was judged to have a schedule similar to that of the shroud. Vehicle ground tests are conducted in parallel to minimize the development time and, consequently, required dedicated hardware as previously indicated in section 7.2

The critical path in this schedule is that of having hardware available to begin the qualification and vehicle ground tests within 2.5 years after go-ahead. Of particular concern are interstage 1-2 and shroud elements since separation tests as well as modal survey and strength tests are required.

A more detailed breakdown of the stage 2 SRM development effort is provided in figure 7.3-2. A major portion of the activity relates to the development of a new nozzle. SRM case elements are not indicated for the test program since it was assumed they could be obtained from the shuttle program. The program would involve the construction of two complete SRMs, which would be refurbished and modified as necessary for a total of five test firings and then refurbished for operational flights.

7.4 FACILITY MODIFICATIONS

Facility modifications can be accomplished within 4 years. Specific efforts required at KSC and VAFB are shown in figure 7.4-1. At KSC, only modifications at the pad have potential impact implications regarding shuttle operations. A shutdown of pad 39B for nearly 6 months in 1989 is assumed for installation of the new crane and umbilical



NOTE: ALL MILESTONES REFLECT COMPLETION

Figure 7.3-1. Vehicle Development Schedule

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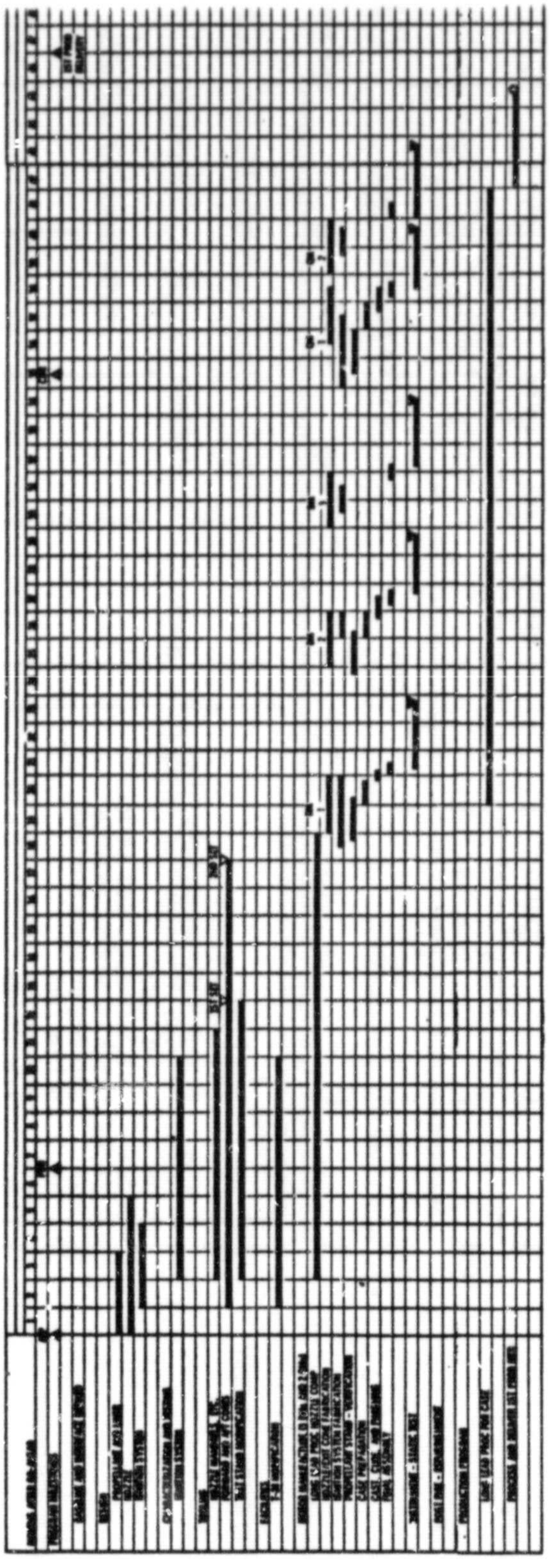


DM – DEVELOPMENT MOTOR
QM – QUALIFICATION MOTOR

Figure 7.3-2. Stage 2 SRM Development

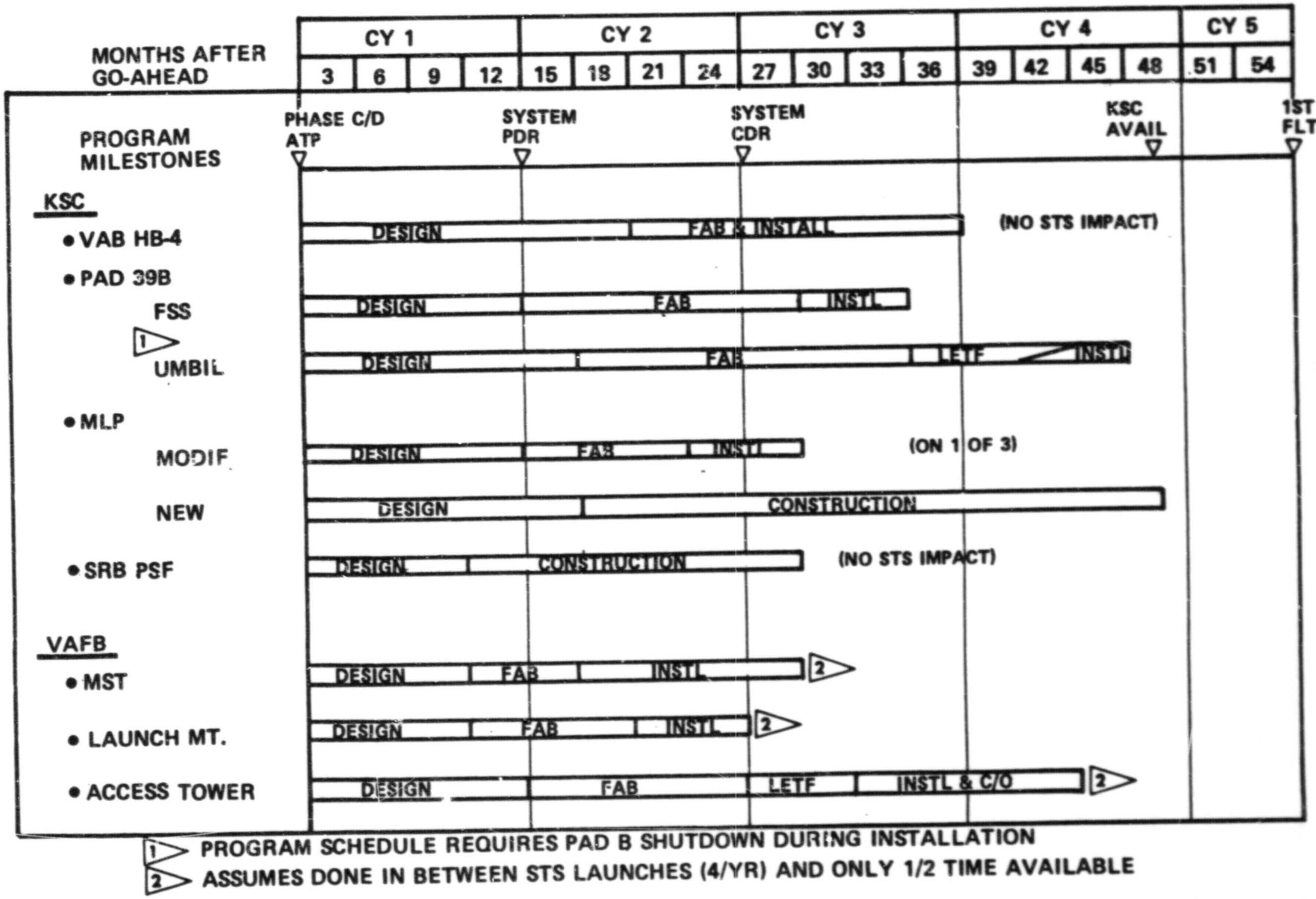


Figure 7.4-1. Facility Modifications

equipment. Should pad installation activities be scheduled to occur between launches, the IOC would slide by another 6 months. Shutdown at that time, however, may not present a problem because each pad theoretically can handle up to 15 launches per year, which would mean a total capability of up to 22 launches even with one pad shut down for 6 months, and only 18 are scheduled. Three MLP's are to be available in the late 1980's, with each capable of supporting 7 flights per year, or a total of 17 or 18 even with one MLP shut down for 6 months of modification. At VFB, the limited number of scheduled STS launches allows time between launches for necessary installations. Consequently, the installation durations reflect a period two times longer than if a dedicated installation operation were performed.

8.0 COST ANALYSIS

This section presents the results of the cost analysis conducted during the study. The overview identifies the approach and methodology and summarizes costs. Subsequent subsections present more detailed descriptions of the major cost categories.

8.1 OVERVIEW

8.1.1 Approach and Scope

The cost analysis had two basic objectives. The first was to provide preliminary data to support the selection of the preferred concept. For the most part, this consisted of data that emphasized differences between concepts (presented in sec. 3.6). The second objective was to develop cost data that would contribute to the assessment of the SRB-X and its comparison with other launch vehicle options. Accordingly, the cost categories judged most significant in satisfying this objective were the design, development, test, and evaluation (DDT&E) cost and the cost per flight as a function of flight rate.

Although total life cycle cost could have been determined, it was judged not significant at this time for the following reasons: (1) a comparison of several SRB-X concepts was not being done in terms of detail cost, (2) uncertainty existed in the mission model for the post-1990 time frame, and (3) without a specific mission model, the number of missions to be flown by SRB-X could not be determined.

8.1.2 Methodology

Costs estimates were developed from a combination of throughput costs provided by NASA and other contractors and costs generated by the Boeing Parametric Cost Model (PCM). PCM estimates costs by using cost-estimating relationships (CER) derived from historical data and inputs of hardware characteristics, including physical description (mass, material), quantities, expressions of complexity and/or degree of modification, and programmatic factors such as schedules and labor rates. Once flight hardware costs are determined, costs for support functions (such as program management, SE&I, etc.) are determined. A detailed description of PCM can be found in reference 3.

8.1.3 Cost Summary

Costs for the SRB-X are summarized in table 8.1.3-1. The total development cost is estimated at $744 million in 1982 dollars. Vehicle development contributes $631 million and facility modifications, $113 million.

Table 8.1.3-1. Program Cost Summary

SRB-X-392

• MILLIONS OF 1982 DOLLARS

DDT&E		COST PER FLIGHT 1	
VEHICLE	631	VEHICLE	82.3
LAUNCH FACILITIES	113	OPERATIONS	18.0
TOTAL	744	TOTAL	100.3

1 FOR 6 SRB-X FLIGHTS/YEAR
COMPARABLE STS COST/FLIGHT (24/YR) IS $80.4M

Cost per flight is estimated at $101 million based on six flights per year. Vehicle cost covering reusable and expendable hardware contributes $82 million and flight and ground operations another $19 million. The corresponding cost per flight for the shuttle during the 1990-1999 time frame is estimated at $80 million.

Further discussion of these cost categories is presented in subsequent sections.

8.2 DDT&E COST

The DDT&E cost includes all effort associated with the design, development, test, and evaluation of the SRB-X hardware elements. Costs identified during this analysis include those for—

a. Flight hardware.
b. System engineering and integration.
c. Software engineering.
d. System test, including hardware and operations.
e. Ground support equipment.
f. Tooling and special test equipment.
g. Spares.
h. Liaison engineering.
i. Data and documentation.
j. Program management.
k. Facilities.

8.2.1 Ground Rules and Assumptions

The following ground rules and assumptions were used to develop the DDT&E cost:

a. Costs in millions of 1982 dollars.
b. PCM used to estimate all Boeing-developed hardware.
c. Boeing-developed hardware to include all interstages, control module, stage 2 skirts.
d. Subcontractors to develop all hardware not included in item c.
e. Costs do not include fee.
f. Qualification and ground test hardware as defined in section 7.2 and summarized as follows:

Element	Number of equivalent units
Stage 1	None
Stage 2	
SRM	2 with 5 firings
Airframe	2.5
Stage 3	2.5
Stage 4	None
Control module	2.5
Interstages	
1-2, 2-3	3 each
3-4	2
Shroud	2

g. No flight test—use of existing, proven hardware and extensive ground test program eliminates need.
h. No class I changes—meaning revisions to requirements after authorization to proceed (ATP).
i. Schedule is nominal in duration.
j. Provide 2.5 sets of GSE.
k. Support effort (SE&I, test, etc.) assumed to be of normal difficulty.

8.2.2 Cost Estimates

The total SRB-X DDT&E cost is estimated at $744 million.

Vehicle DDT&E and First Flight Unit (FFU). The vehicle contribution to the DDT&E cost is estimated at $631 million. A breakdown of the cost is presented in table 8.2.2-1. Approximately 37% of the cost is associated with the flight hardware while 40% relates to the system test effort.

A further breakdown of DDT&E flight hardware and first flight unit costs is presented in table 8.2.2-2. In terms of DDT&E, stage 2 represents the largest contribution because it is essentially a new stage. A breakdown of the main elements of stage 2 design and development includes:

Table 8.2.2-1. Vehicle DDT&E Cost

		MILLIONS OF 1982 DOLLARS
• FLIGHT HARDWARE (DES & DEV)		171
• SYSTEM ENGINEERING & INTEGRATION		33
• SOFTWARE ENGINEERING		35
• SYSTEM TEST		250
• FLIGHT HARDWARE	223	
• TEST OPERATIONS	27	
• GROUND SUPPORT EQUIPMENT		24
• TOOLING AND SPECIAL TEST EQUIPMENT		31
• SPARES		20
• LIAISON ENGINEERING		7
• DATA/DOCUMENTATION		8
• PROGRAM MANAGEMENT		52
TOTAL		631

Table 8.2.2-2. *Flight Hardware DDT&E and First Flight Unit Cost*

SRB-X-394

• MILLIONS OF 1982 DOLLARS

SYSTEM ELEMENT	DDT&E		FIRST FLIGHT UNIT (FFU)
	DES & DEV	TEST [1]	
STAGE 1	2	0	22.0
STAGE 2	58	70	22.2
STAGE 3	25	24	13.0
STAGE 4	2	0	–
CONTROL MODULE	45	62	26.0
INTERSTAGE 1-2	25	24	9.0
INTERSTAGE 2-3 & 3-4	2	2	0.9
SHROUD	12	15	8.0
ASSY & C/O & OPS	–	53	13.1
TOTALS	171	250	114.2

[1] QUAL & SYS LEVEL TEST HARDWARE AND OPERATIONS

Element	$ (millions)	Basis
Structures	40	Boeing PCM
SRM	[illegible]	Thiokol
TVC	3	Boeing PCM
Auxiliary propulsion	3	Boeing PCM
Electrical/instrumentation	4	Boeing PCM

Stage 3 costs, provided by Martin Marietta, reflect modifications for increasing tank length ($15 million) and longer engine burn time ($10 million). The control module design cost breakdown was estimated as follows:

	$ (millions)
Structures	3
Propulsion	3
Avionics	37
Electrical/instrumentation	3

Interstage 1-2, consisting of the large strut systems and shell, also contributed significantly to the cost. Shroud costs were provided by Lockheed Missile and Space Company.

The estimated first unit cost for the vehicle is $114 million. Stage 1 cost reflects the average cost assumed for the STS SRB's. Stage 2, at $22 million, is primarily made up of the SRM at $9.7 million and the structure at $6 million. Most of the control module costs involve the avionics ($16 million). Stage 3 and shroud estimates were provided by Martin Marietta and Lockheed, respectively.

Facility Cost. Total costs associated with facility modifications and new equipment were estimated at $113 million, as indicated in table 8.2.2-3. The KSC contribution of $63 million has as its major contribution the FSS modifications involving umbilical provisions, structural beefup, and new crane installation. VAB modification costs primarily involve the new access platforms required. Modifications at VAFB amount to $50 million with umbilical provisions and access platforms within the MST, access tower, and at the launch mount being the major contributors.

SRB-X-388

Table 8.2.2-3. Facilities Cost

- COST IN MILLIONS OF 1982 DOLLARS

KSC		VAFB (SLC-6)	
• VAB	16.0	• MST	21.5
• MLP [1]	3.5	• LAUNCH MOUNT	12.0
• PAD-39B		• ACCESS TOWER	11.0
FSS	30.5		
RSS	7.5		
• LPS	5.0	• LPS	5.0
• SRB PSF [2]	0.5	• SRB PSF	0.5 [2]
	63.0		50.0

TOTAL $113M

[1] MODIFIED—NEW DEDICATED UNIT $50M

[2] SRB-X PECULIAR – NEW DEDICATED WOULD BE $6M

8.3 COST PER FLIGHT

The cost-per-flight estimate includes the following factors:

a. Production of expendable hardware.

b. Production and refurbishment of reusable hardware.

c. Propellant cost.

d. Launch operations including vehicle processing, assembly, and checkout; ground systems and operations; cargo checkout; and sustaining and logistics support.

e. Flight operations including mission operations, program management, program support, and payload integration.

f. Network support.

8.3.1 Ground Rules and Assumptions

The following ground rules and assumptions were used to develop the cost-per-flight estimate:

a. Items a. through e., as specified for DDT&E in section 8.2.1.

b. 10-year operational program—1990 through 1999.

c. STS cost base: NASA assessment case for STS pricing (1982) assuming 24 flights per year.

d. STS cost to reflect FY 1990 values for the assessment case—no significant learning thereafter. Costs presented in section 8.3.2 will indicate these values.

e. SRB-X flight rate of 2, 6, or 10 per year. Several rates are considered because mission models, STS flight capability, and rates through the year 2000 are only in preliminary phases of planning. Preliminary capture studies, however, have indicated that up to 25% of future missions could be performed with an unmanned launch vehicle. The assumed distribution of SRB-X and STS flights for two considered flight rates follows:

24 flights per year

	KSC	VAFB	Total
STS	14	4	18
SRB-X	4	2	6
	18	6	24

40 flights per year

	KSC	VAFB	Total
STS	24	6	30
SRB-X	6	4	10
	30	10	40

f. Stage 1

1. Same SRB's as for STS.
2. Use FY 1990 values but with adjustment for FWC. The cost impact for FWC is estimated at less than $1 million based on 2 reuses of the composite elements and 19 reuses of steel elements. The key to low delta cost is recovery and reuse of the steel components. Further details concerning FWC cost are presented in table 8.3.1-1.

g. Stage 2

1. Total production run (new stage).
2. SRM learning, 96%.
3. Structure learning, 90%.
4. Subsystems learning, 92%.

h. Stage 3—annual production rate. A significant number of Titan second stages have been produced; therefore, no further learning is assumed. A variation in production rate will influence the unit cost.

i. Control module

1. Total production run (new element).
2. Average learning, 92%.

j. Interstages

1. Total production run (new elements).
2. Average learning, 90%.

k. Shroud

1. Total production run (new element).
2. Average learning, 92%.

l. Launch and flight operations—use STS FY 1990 values with appropriate adjustments for vehicle differences.

8.3.2 Cost Estimate

SRB-X cost per flight is estimated at $101 million versus $80 million for the shuttle during the 1990 to 1999 time period. Table 8.3.2-1 shows a breakdown of the cost and SRB-X sensitivity to flight rate. It should be noted that values for R&PM, GSE spares, and contract administration are not included. Higher SRB-X vehicle costs are primarily because of the lower annual flight rate (6 versus 24) and more expendable hardware (only stage 1 is reusable). Operations costs are lower, however, because the relatively complex manned orbiter is not present, which simplifies vehicle processing, mission planning, and crew training. A breakdown of the operations is presented in table 8.3.2-2. The SRB-X

Table 8.3.1-1. FWC SRM Relative Cost

SRB-X-409

- 4 SEGMENT SRM
- PRELIMINARY FWC ESTIMATE

UNIT COST

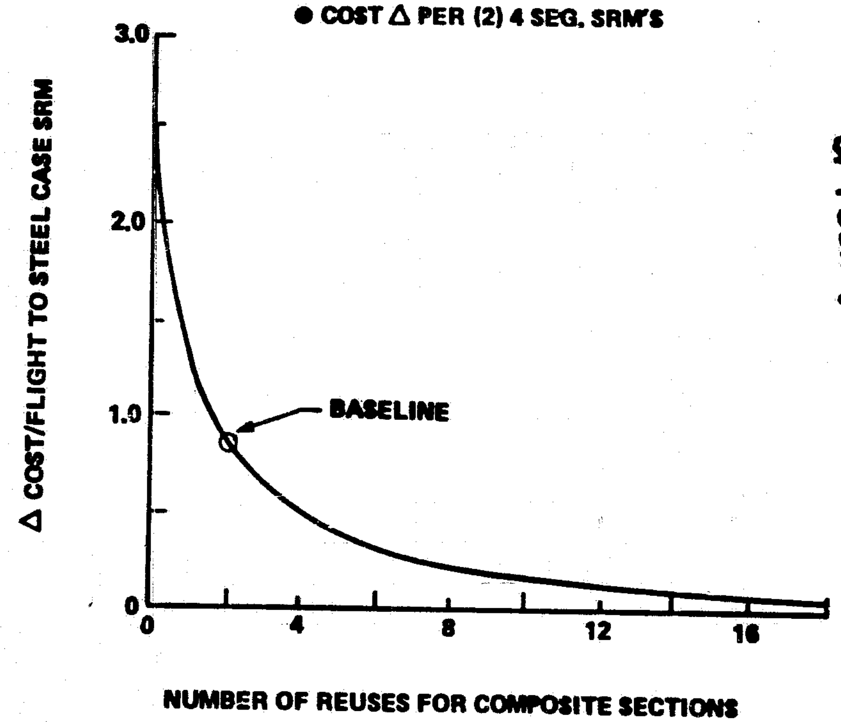
- FWC SRM $300,000 CHEAPER THAN STEEL CASE SRM
- NO DIFFERENCE IN OTHER SRB ELEMENTS
- COMPONENT % OF UNIT COST

COMPONENT	STEEL CASE	FILAMENT CASE
DOMES – STEEL	20	21
CASE		
COMPOSITE SECT.		36
STEEL SECT.	80	11
STEEL ADAPTERS		32

* 64% OF FWC IS REUSEABLE STEEL

COST SENSITIVITY TO REUSE

- COST Δ PER (2) 4 SEG. SRM'S



* KEY IS RECOVERY OF SRB

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Table 8.3.2-1. Cost Per Flight

- NASA 1982 ASSESSMENT CASE FOR 1986 - 1988 PRICING
- 10 YEAR PROGRAM — 1990 THROUGH 1999
- MILLIONS OF 1982 DOLLARS
- LEO DESTINATION

SRB-X AT 6 FLIGHTS/YEAR		STS AT 24/YEAR	
VEHICLE [1]	(82.3)	VEHICLE	(50.3)
STAGE 1	22.0	SRB	21.2
STAGE 2	16.3	ET	16.6
STAGE 3	10.3	ORBITER	7.8
CONTROL MODULE [3]	20.4	CREW EQUIPMENT	0.7
INTERSTAGE 1-2	6.5	MAIN ENG	2.7
INTERSTAGE 2-3, 3-4	0.5	PROPELLANT	1.3
SHROUD	6.3		
OPERATIONS	(19.0)	OPERATIONS	(29.3)
NETWORK	0.2	NETWORK	0.2
LAUNCH	10.0	LAUNCH	15.9
FLIGHT	8.8	FLIGHT	13.2
TOTAL [2]	101.3	TOTAL [2]	79.6

[1] EACH ITEM INCLUDES 13% FOR PROGRAM MANAGEMENT, LIAISON, SPARES

[2] NOT ASSESSED: R&PM, GSE SPARES AND CONT. ADMIN.

[3] POTENTIALLY COULD BE RECOVERED

NOTE: FOR GEO TRANSFER PAYLOAD
SRB-X NO EXTRA COST
STS 15 - 20M EXTRA FOE EQUIVALENT CAPABILITY

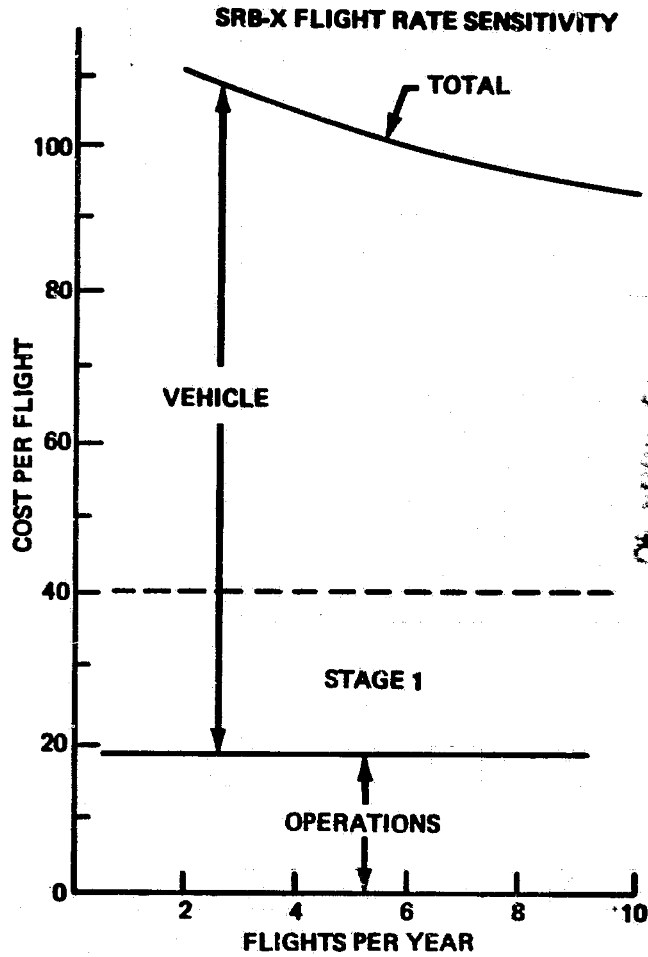

Table 8.3.2-2. Operations Cost Breakdown

FLIGHT OPERATIONS ($M 1982 DOLLARS)

	STS	SRB-X	SRB-X RATIONALE
MISSION OPERATIONS	4.2	3.2	NO REENTRY/RECOVERY/ABORT
CREW OPERATIONS	1.5	0	NO FLIGHT CREW
PAYLOAD INTEGRATION	0.6	0.4	NO CREW INTERFACES
ENGINEERING SUPPORT	1.5	0.8	NO LIFE SCIENCE SUPPORT
PROGRAM MANAGEMENT	2.9	2.3	LESS COMPUTATION; LESS COMPLEXITY
PROGRAM SUPPORT	1.0	0.6	LESS COMPUTATION; FEWER JSC INTERFACES
PROGRAM ADJUSTMENT	1.5	1.5	
TOTAL	13.2	8.8	

LAUNCH OPERATIONS ($M 1982 DOLLARS)

	STS	SRB-X
VEHICLE PROCESSING	(8.0)	(2.7)
ORBITER	6.0	0
EXTERNAL TANK	0.8	0
SRB (STAGE 1)	1.2	1.2
STAGE 2	—	0.2
STAGE 3 AND INTERSTAGE	—	0.9
CONTROL MODULE	—	0.3
SHROUD	—	0.1
GROUND SYSTEM AND OPERATIONS	(5.1)	(5.1)
SUSTAINING ENGINEERING	(0.6)	(0.4) [1]
LOGISTICS SUPPORT	(0.4)	(0.3) [1]
CARGO CHECKOUT	(1.0)	(1.0)
OTHER	(0.8)	(0.5) [1]
TOTAL	15.9	10.0

[1] LESS DUE TO LESS VEHICLE PROCESSING

may be less expensive, however, on those flights involving high orbits or inclinations or GEO transfer because the basic vehicle can perform these missions, while the shuttle would require an additional transportation element.

SRB-X cost per flight could reach as low as $90 million if there are 10 flights per year. The relatively small sensitivity to flight rate occurs primarily because two cost elements (stage 1 and operations) that comprise nearly 40% of the basic cost are essentially the same as for the shuttle, and no significant reductions are expected after 1990.

9.0 PROGRAM RISK

Program risks were assessed in four areas: technical, schedule, cost, and programmatics. The overall assessment is that SRB-X would be a low-risk program primarily because of its extensive use of existing or modified systems and operations. No new technology development areas were identified.

No significant technical risk is foreseen. Modifications suggested for the stage 2 SRM and for stage 3 are within state-of-the-art capability; major new hardware consists only of structural shrouds, interstages, or skirts; the control module uses IUS or shuttle hardware; and flight and ground operations are similar to those for the shuttle.

The primary risk in the suggested schedule concerns the availability of appropriate hardware in 2 to 2½ years to begin integrated vehicle testing. No allowance was made for failure in any major test. Such a situation, however, is unlikely because of the extensive data base available. Inclusion of the facility pathfinder vehicle should improve the likelihood of an on-schedule first launch.

Developmental cost risk has been minimized by extensive use of existing systems, subsystems, and facilities and by availability of separate hardware for each major system test. Recurring costs, however, could be influenced by low production rates and their subsequent impact on lot charges or loss of qualified suppliers. Uncertainty in the number of stage 1 FWC SRB reuses is not an issue because only two reuses are assumed. It is important, however, that SRB's always be recovered so their expensive steel elements can be reused. The mixed-fleet concept, itself, presents an uncertainty in the area of operation costs. The current estimate assumes 100% interchangeability between SRB-X and shuttle ground and flight operations personnel. If not the case, operation costs would increase.

Programmatic risk deals with aspects beyond the control of the SRB-X program. A major impact could be the availability of Titan stage II (SRB-X stage 3) because final production is scheduled for 1985-1986 and SRB-X IOC is not until 1990. Reactivation of the production line after several years has been estimated at \$30 to \$40 million. An alternative is an MX-type first stage; however, as previously mentioned, there would be an approximate 7000-lb reduction in LEO payload capability. Several factors significantly influence SRB-X effectiveness in terms of number of flights flown and impact on recurring costs. These factors include mission model and payload characteristics and STS flight rate capability as influenced by fleet size, turnaround time, and the availability of facilities.

10.0 LAUNCH VEHICLE ASSESSMENT

The space transportation system may be most effective when use is made of the shuttle and an unmanned launch vehicle. Previous investigations (ref. 4) have considered several non-SDV's for the unmanned vehicle role. These include growth Atlas with improved booster and strapons, growth Titan with stretch core and seven-segment SRM's, and Ariane 5. Payload capability, cost, and schedule characteristics of these candidates, SRB-X, and the shuttle are presented in table 10.0-1.

Table 10.0-2 is an assessment of the SRB-X in relation to the shuttle and to non-SDV's. Compared to the latter, the SRB-X offers considerable advantages in payload capability, recurring costs, and flexibility for alternative missions. A disadvantage is that higher development costs would also occur. IOC may not be significantly different if ATP is the same for all candidates. Relative to the shuttle, SRB-X can provide increased capability in payload envelope and better performance to high orbits or inclinations without an upper stage. The unmanned launch, however, does not allow hands-on, on-orbit checkout or immediate recovery of payload, should the need arise.

Table 10.0-1. *Launch Vehicle Characteristics*

PAYLOAD (K POUNDS)	ATLAS II (SSM) 3	TITAN 34D7	ARIANE 5	SRB-X	STS (STD.) 5
100 NM/28.5 DEG	32	38	——	61	65
100 NM/POLAR	28	32	——	49	32
GEO TRANSFER	14	20 3	10	18	REQUIRES UPPER STG
GEO INJECTION 1	6.7	9	6.2	12 6	12 6
NON-RECURRING ($M)	170	155	?	750	——
COST/FLT–($M) 7	75	80	65	105	80 2
COST/LB ($$10^3$)					
GEO TRANSFER	5.4	5.3	6.5	5.5	5.5 4
GEO INJECTION	11.2	11.6	10.5	10.0	8.7
IOC (DIFF DATE FOR ATP)	1986	1987	1990	1990	NOW

1 ALL OPTIONS USE CENTAUR D-IT EXCEPT ARIANE FOR GEO
2 24 FLTS/YR —— POST 1990 COST PREDICTION
3 WITH D-IT FOR ALL MISSIONS OR MISSION INDICATED
4 IF APPROPRIATE UPPER STG AVAIL
5 SPEC VALUE
6 CAPABLE OF 16K
7 4 FLT/YR EXCEPT AS NOTED

Table 10.0-2. SRB-X Assessment

SRB-X-410

- SRB-X RELATIVE TO SHUTTLE
  - ADVANTAGES
    - LARGER PAYLOAD ENVELOPE POTENTIAL
    - BETTER LEO HIGH ORBIT/HIGH INCL. AND GEO TRANSFER PAYLOAD
    - COMPARABLE COST/POUND FOR ABOVE DESTINATIONS IF STS INCORPORATES APPROPRIATE UPPER STAGE
    - COMPARABLE GEO PAYLOAD
    - COMPARABLE OR BETTER COST/POUND TO ALL DESTINATIONS IF CONTROL MODULE RECOVERED
  - DISADVANTAGES
    - PAYLOAD NOT RECOVERABLE FOR ABORT SITUATION
    - NO ON-ORBIT CHECKOUT POTENTIAL
- SRB-X RELATIVE TO NON-SHUTTLE DERIVED VEHICLES
  - ADVANTAGES
    - BETTER PAYLOAD TO ALL DESTINATIONS
    - LARGER PAYLOAD ENVELOPE POTENTIAL
    - COMPARABLE OR LOWER COST/POUND TO DESTINATION
    - PAYLOAD INTERCHANGEABILITY WITH STS
    - CONTRIBUTES TO REDUCING STS COST
  - DISADVANTAGES
    - HIGHER DEVELOPMENT COST
    - POTENTIALLY LONGER TO IOC AFTER ATP

11.0 SUPPORTING RESEARCH AND TECHNOLOGY

A guiding philosophy during the performance of the SRB-X study was that, if at all possible, the vehicle should use existing technology. The study results indicate a vehicle could be developed that would satisfy performance requirements without the need for any new technology.

12.0 REFERENCES

1. Boeing Aerospace Company, "Shuttle Derived Cargo Launch Vehicle Concept Evaluation Study," Final Report dated September 1982, NASA Contract NAS8-34599.

2. Martin Marietta Corporation, "Shuttle Derived (SDV) Technology Requirements Study," Phase II Final Report dated May 1982, NASA Contract NAS8-34183.

3. Boeing Aerospace Company, "Orbit Transfer Vehicle Concept Definition Study," Final Report, Volume 6, Boeing document D180-26090-6, NASA Contract NAS8-33532, 1980.

4. The Aerospace Corporation, "Systems Analysis of National Space Launch Possibilities," report by Dr. B. P. Leonard, June 1982.

APPENDIX A—FIRST SCREENING RESULTS

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Appendix A-1 Class A LEO Capability (Sheet 1)

CONFIG CODE	STRAP-ON	STAGE 1	STAGE 2	STAGE 3	STAGE 4	PAYLOAD	% PAYLOAD
4 2 2 5	4SRB 4X1 FB	SRB 1X4 SD	SRB 1X2	SRB 1X1	CENT #B	79575.0	2 .
4 2 2 3	4SRB 4X1 FB	SRB 1X4 SD	SRB 1X2	TIT34D 2ND	CENT #B	78253.3	2.13
4 2 2 5	4SRB 4X1 FB	SRB 1X4 SD	SRB 1X2	S-1	CENT #B	73112.1	2.1
3 2 2 5	4SRB 3X1 F5	SRB 1X4 SD	SRB 1X2	SRB 1X1	CENT #B	73987.4	2.06
3 2 2 3	4SRB 3X1 F5	SRB 1X4 SD	SRB 1X2	TIT34D 2ND	CENT #B	72865.9	2.21
3 2 2 5	4SRB 3X1 F5	SRB 1X4 SD	SRB 1X2	S-1	CENT #B	72729.8	2.19
2 2 2 5	4TIT3 4TH	SRB 1X4 SD	SRB 1X2	SRB 1X1	CENT #B	72647.9	2.1
4 2 1 5	4SRB 4X1 FB	SRB 1X4 SD	SRB 1X1	SRB 1X1	CENT #B	72444.3	1.97
4 2 1 3	4SRB 4X1 F3	SRB 1X4 SD	SRB 1X1	TIT34D 2ND	CENT #B	71572.3	2.12
2 2 2 3	4TIT3 3TH	SRB 1X4 SD	SRB 1X2	TIT34D 2ND	CENT #B	71352.0	2.26
4 2 1 5	4SRB 4X1 F5	SRB 1X4 SD	SRB 1X1	S-1	CENT #B	71257.2	2.05
2 2 2 5	4TIT3 ATH	SRB 1X4 SD	SRB 1X2	S-1	CENT #B	71249.2	2.23
4 2 2 3	3SRB 4X1 F3	SRB 1X4 SD	SRB 1X2	TIT34D 2ND	CENT D1-T	70881.9	1.94
4 2 2 5	3SRB 4X1 F4	SRB 1X4 SD	SRB 1X2	S-1	CENT D1-T	70639.6	1.92
4 2 2 5	3SRB 4X1 F5	SRB 1X4 SD	SRB 1X2	SRB 1X1	CENT D1-T	70234.7	1.77
4 2 2 4	4SRB 4X1 F5	SRB 1X4 SD	SRB 1X2	S-2	CENT #B	69422	1.9 .
1 2 2 5	4SRB 2X1 F2	SRB 1X4 SD	SRB 1X2	SRB 1X1	CENT #B	68459.5	2.12
3 2 1 5	4SRB 3X1 F4	SRB 1X4 SD	SRB 1X1	SRB 1X1	CENT #B	67147.1	2.04
1 2 2 3	4SRB 2X1 F5	SRB 1X4 SD	SRB 1X2	TIT34D 2ND	CENT #B	67073.5	2.31
1 2 2 5	4SRB 2X1 F8	SRB 1X4 SD	SRB 1X2	S-1	CENT #B	66949.5	2.28
3 2 1 3	4SRB 3X1 F9	SRB 1X4 SD	SRB 1X1	TIT34D 2ND	CENT #B	66554	2.23
3 2 1 5	4SRB 3X1 F5	SRB 1X4 SD	SRB 1X1	S-1	CENT #B	66231.9	2.19
3 2 2 3	3SRB 3X1 F4	SRB 1X4 SD	SRB 1X2	TIT34D 2ND	CENT D1-T	65876.8	2.01
2 2 1 5	4TIT3 3TH	SRB 1X4 SD	SRB 1X1	SRB 1X1	CENT #B	65663.0	2.07
3 2 2 5	4SRB 3X1 F4	SRB 1X4 SD	SRB 1X2	S-1	CENT D1-T	65555.5	1.95
3 2 2 5	3SRB 3X1 F5	SRB 1X4 SD	SRB 1X2	SRB 1X1	CENT D1-T	64975.6	1.87
1 2 1 3	4SRB 4X1 F-	SRB 1X4 SD	SRB 1X1	TIT34D 2ND	CENT D1-T	64761.5	1.93
2 2 1 3	4TIT3 4TH	SRB 1X4 SD	SRB 1X1	TIT34D 2ND	CENT #B	64727.4	2.27
4 2 2 5	5SRB 4X1 F-	SRB 1X4 SD	SRB 1X2	SRB 1X1	S-3	64545.6	1.62
2 2 1 5	1TIT3 4TH	SRB 1X4 SD	SRB 1X1	S-1	CENT #B	64453.5	2.23
3 2 2 4	4SRB 3X1 F5	SRB 1X4 SD	SRB 1X2	S-2	CENT #B	64394.7	1.9-
2 2 2 3	4TIT3 4TH	SRB 1X4 SD	SRB 1X2	TIT34D 2ND	CENT D1-T	64352.4	2.05
4 2 1 5	3SRB 4X1 F5	SRB 1X4 SD	SRB 1X1	S-1	CENT D1-T	64249.3	1.9
2 2 2 5	3TIT3 3TH	SRB 1X4 SD	SRB 1X2	S-1	CENT D1-T	64134	2.03
4 2 2 3	5SRB 4X1 F5	SRB 1X4 SD	SRB 1X2	TIT34D 2ND	S-3	63837.0	1.74
4 2 2 5	5SRB 4X1 F5	SRB 1X4 SD	SRB 1X2	S-1	S-3	63641.5	1.72
2 2 2 5	3TIT3 3TH	SRB 1X4 SD	SRB 1X2	SRB 1X1	CENT D1-T	63618.2	1.85
4 2 1 4	4SRB 4X1 F4	SRB 1X4 SD	SRB 1X1	S-2	CENT #B	63521.4	1.9
4 2 1 5	3SRB 4X1 F5	SRB 1X4 SD	SRB 1X1	SRB 1X1	CENT D1-T	63400.6	1.73
2 2 2 4	4TIT3 3TH	SRB 1X4 SD	SRB 1X2	S-2	CENT #B	62955.2	2.02
4 2 2 2	1SRB 4X1 F-	SRB 1X4 SD	SRB 1X2	CENT #B	TIT3 TRAN	62379.0	1.77
4 2 2 2	2SRB 4X1 F-	SRB 1X4 SD	SRB 1X2	CENT #B	IUS 2STAGE	62371.3	1.72
1 2 1 5	4SRB 2X1 F4	SRB 1X4 SD	SRB 1X1	SRB 1X1	CENT #B	61467.0	2.12
1 2 1 3	4SRB 2X1 F-	SRB 1X4 SD	SRB 1X1	TIT34D 2ND	CENT #B	61054.5	2.35
4 2 2 4	3SRB 4X1 F5	SRB 1X4 SD	SRB 1X2	S-2	CENT D1-T	61031.3	1.69
1 2 1 5	4SRB 2X1 F4	SRB 1X4 SD	SRB 1X1	S-1	CENT #B	60740.6	2.31
4 2 2 2	0SRB 4X1 F-	SRB 1X4 SD	SRB 1X2	CENT #B	-NULL STG-	60572.9	1.69
1 2 2 3	3SRB 2X1 F4	SRB 1X4 SD	SRB 1X2	TIT34D 2ND	CENT D1-T	60352.6	2.1
1 2 2 5	3SRB 2X1 F0	SRB 1X4 SD	SRB 1X2	S-1	CENT D1-T	60113.4	2.07
3 2 1 3	3SRB 3X1 F9	SRB 1X4 SD	SRB 1X1	TIT34D 2ND	CENT D1-T	60073.7	2.03
3 2 1 5	3SRB 3X1 F2	SRB 1X4 SD	SRB 1X1	S-1	CENT D1-T	59571.4	1.99
3 2 2 5	5SRB 3X1 F9	SRB 1X4 SD	SRB 1X2	SRB 1X1	S-3	59331.5	1.65
1 2 2 5	3SRB 2X1 F5	SRB 1X4 SD	SRB 1X2	SRB 1X1	CENT D1-T	59290.7	1.87
1 2 2 4	4SRB 2X1 F4	SRB 1X4 SD	SRB 1X2	S-2	CENT #B	59023.1	2.06
3 2 1 4	4SRB 3X1 F4	SRB 1X4 SD	SRB 1X1	S-2	CENT #B	58885.2	1.99
3 2 2 3	5SRB 3X1 F8	SRB 1X4 SD	SRB 1X2	TIT34D 2ND	S-3	58811.9	1.79
3 2 2 5	5SRB 3X1 F5	SRB 1X4 SD	SRB 1X2	S-1	S-3	58621.8	1.77
3 2 1 5	3SRB 3X1 F4	SRB 1X4 SD	SRB 1X1	SRB 1X1	CENT D1-T	58394.1	1.79
2 2 1 3	3TIT3 3TH	SRB 1X4 SD	SRB 1X1	TIT34D 2ND	CENT D1-T	58296.0	2.05
2 2 2 5	5TIT3 3TH	SRB 1X4 SD	SRB 1X2	SRB 1X1	S-3	58080.7	1.69

Appendix A-1 Class A LEO Capability (Sheet 2)

CONFIG CODE	STRAP-ON	STAGE 1	STAGE 2	STAGE 3	STAGE 4	PAYLOAD	% PAYLOAD
4 2 1 5	5SRB 4X1 FB	SRB 1X4 SO	SRB 1X1	SRB 1X1	S-3	57842.3	1.5
2 2 1 5	3TIT3 3TH	SRB 1X4 SO	SRB 1X1	S-1	CENT D1-T	57857.4	2.0
4 2 1 3	5SRB 4X1 FB	SRB 1X4 SO	SRB 1X1	TIT34D 2ND	S-3	57664.5	1.7
3 2 2 2	1SRB 3X1 FB	SRB 1X4 SO	SRB 1X2	CENT 48	TIT3 TRAN	57415.5	1.7
2 2 2 3	4TIT3 3TH	SRB 1X4 SO	SRB 1X2	TIT34D 2ND	S-3	57390.9	1.8
3 2 2 2	2SRB 3X1 FB	SRB 1X4 SO	SRB 1X2	CENT 48	IUS 2STAGE	57371.3	1.7
4 2 1 5	5SRB 4X1 FB	SRB 1X4 SO	SRB 1X1	S-1	S-3	57290.4	1.6
2 2 2 5	5TIT3 4TH	SRB 1X4 SO	SRB 1X2	S-1	S-3	57237.5	1.8
2 2 1 4	4TIT3 4TH	SRB 1X4 SO	SRB 1X1	S-2	CENT 48	57187.2	2.0
2 2 1 5	3TIT3 4TH	SRB 1X4 SO	SRB 1X1	SRB 1X1	CENT D1-T	56971	1.82
4 2 1 2	1SRB 4X1 FB	SRB 1X4 SO	SRB 1X1	CENT 48	TIT3 TRAN	56832.3	1.7
4 2 1 2	2SRB 4X1 FB	SRB 1X4 SO	SRB 1X1	CENT 48	IUS 2STAGE	56710.1	1.7
4 2 2 3	2SRB 4X1 FB	SRB 1X4 SO	SRB 1X2	TIT34D 2ND	IUS 2STAGE	56449.2	1.5
3 2 2 4	3SRB 3X1 FB	SRB 1X4 SO	SRB 1X2	S-2	CENT D1-T	56384.0	1.7
4 2 2 3	1SRB 4X1 FB	SRB 1X4 SO	SRB 1X2	TIT34D 2ND	TIT3 TRAN	56156.6	1.5
4 2 2 5	2SRB 4X1 FB	SRB 1X4 SO	SRB 1X2	S-1	IUS 2STAGE	56016.4	1.5
2 2 2 2	1TIT3 4TH	SRB 1X4 SO	SRB 1X2	CENT 48	TIT3 TRAN	55969.7	1.8
2 2 2 2	2TIT3 4TH	SRB 1X4 SO	SRB 1X2	CENT 48	IUS 2STAGE	55919.6	1.8
4 2 1 1	3SRB 4X1 FB	SRB 1X4 SO	SRB 1X1	S-2	CENT D1-T	55909.0	1.6
3 2 2 2	4SRB 3X1 FB	SRB 1X4 SO	SRB 1X2	CENT 48	-NULL 4TH-	55845.7	1.7
4 2 1 2	0SRB 4X1 FB	SRB 1X4 SO	SRB 1X1	CENT 48	-NULL 4TH-	55825.9	1.6
4 2 2 5	1SRB 4X1 FB	SRB 1X4 SO	SRB 1X2	S-1	TIT3 TRAN	55714.0	1.5
4 2 2 1	5SRB 4X1 FB	SRB 1X4 SO	SRB 1X2	S-2	S-3	55247.9	1.5
2 2 2 4	3TIT3 4TH	SRB 1X4 SO	SRB 1X2	S-2	CENT D1-T	55028.0	1.7
1 2 1 3	3SRB 2X1 FB	SRB 1X4 SO	SRB 1X1	TIT34D 2ND	CENT D1-T	54937.7	2.1
4 2 2 1	2SRB 4X1 FB	SRB 1X4 SO	SRB 1X2	CENT D1-T	IUS 2STAGE	54510	1.51
2 2 2 2	0TIT3 3TH	SRB 1X4 SO	SRB 1X2	CENT 48	-NULL 4TH-	54440.5	1.7
1 2 1 5	3SRB 2X1 FB	SRB 1X4 SO	SRB 1X1	S-1	CENT D1-T	54438	2.09
4 2 2 1	1SRB 4X1 FB	SRB 1X4 SO	SRB 1X2	CENT D1-T	TIT3 TRAN	54248	1.51
1 2 2 5	5SRB 2X1 FB	SRB 1X4 SO	SRB 1X2	SRB 1X1	S-3	53839.2	1.5
1 2 1 4	4SRB 2X1 FB	SRB 1X4 SO	SRB 1X1	S-2	CENT 48	53819.3	2.1
4 2 2 5	2SRB 4X1 FB	SRB 1X4 SO	SRB 1X2	SRB 1X1	IUS 2STAGE	53642.5	1.3
1 2 2 3	5SRB 2X1 FB	SRB 1X4 SO	SRB 1X2	TIT34D 2ND	S-3	53437.5	1.6
1 2 2 5	5SRB 2X1 FB	SRB 1X4 SO	SRB 1X2	S-1	S-3	53253.2	1.6
1 2 1 5	3SRB 2X1 FB	SRB 1X4 SO	SRB 1X1	SRB 1X1	CENT D1-T	53055.5	1.5
3 2 1 3	5SRB 3X1 FB	SRB 1X4 SO	SRB 1X1	TIT34D 2ND	S-3	53020.5	1.7
3 2 1 5	5SRB 3X1 FB	SRB 1X4 SO	SRB 1X1	SRB 1X1	S-3	52989.5	1.6
3 2 1 5	5SRB 3X1 FB	SRB 1X4 SO	SRB 1X1	S-1	S-3	52640.3	1.7
4 2 2 5	1SRB 4X1 FB	SRB 1X4 SO	SRB 1X2	SRB 1X1	TIT3 TRAN	52556.3	1.3
3 2 1 2	1SRB 3X1 FB	SRB 1X4 SO	SRB 1X1	CENT 48	TIT3 TRAN	52255.7	1.7
1 2 2 2	1SRB 2X1 FB	SRB 1X4 SO	SRB 1X2	CENT 48	TIT3 TRAN	52184	1.83
3 2 1 2	2SRB 3X1 FB	SRB 1X4 SO	SRB 1X1	CENT 48	IUS 2STAGE	52098	1.77
1 2 2 2	2SRB 2X1 FB	SRB 1X4 SO	SRB 1X2	CENT 48	IUS 2STAGE	52020.2	1.
4 2 2 3	0SRB 4X1 FB	SRB 1X4 SO	SRB 1X2	TIT34D 2ND	-NULL 4TH-	51921.9	1.
3 2 2 3	2SRB 3X1 FB	SRB 1X4 SO	SRB 1X2	TIT34D 2ND	IUS 2STAGE	51647.4	1.5
3 2 1 4	3SRB 3X1 FB	SRB 1X4 SO	SRB 1X1	S-2	CENT D1-T	51633.7	1.7
2 2 1 5	5TIT3 3TH	SRB 1X4 SO	SRB 1X1	SRB 1X1	S-3	51615.3	1.
3 2 1 2	0SRB 3X1 FB	SRB 1X4 SO	SRB 1X1	CENT 48	-NULL 4TH-	51477.9	1.
3 2 2 3	1SRB 3X1 FB	SRB 1X4 SO	SRB 1X2	TIT34D 2ND	TIT3 TRAN	51429	1.59
1 2 2 4	3SRB 2X1 FB	SRB 1X4 SO	SRB 1X2	S-2	CENT D1-T	51424.6	1.
2 2 1 3	5TIT3 3TH	SRB 1X4 SO	SRB 1X1	TIT34D 2ND	S-3	51301.1	1.
3 2 2 5	2SRB 3X1 FB	SRB 1X4 SO	SRB 1X2	S-1	IUS 2STAGE	51247.2	1.
[illegible] 1 2 3	4-NULL 0TH-	SRB 1X4	SRB 1X2	TIT34D 2ND	CENT [illegible]	51023.1	2.
[illegible] 1 2 5	4-NULL 0TH-	SRB 1X4	SRB 1X2	S-1	CENT [illegible]	51000.0	2.
2 2 1 5	5TIT3 3TH	SRB 1X4 SO	SRB 1X1	S-1	S-3	50983.1	1.
3 2 2 5	1SRB 3X1 FB	SRB 1X4 SO	SRB 1X2	S-1	TIT3 TRAN	50975.5	1.
4 2 1 3	2SRB 4X1 FB	SRB 1X4 SO	SRB 1X1	TIT34D 2ND	IUS 2STAGE	50888.2	1.
4 2 2 5	0SRB 4X1 FB	SRB 1X4 SO	SRB 1X2	S-1	-NULL 4TH-	50816.2	1.
1 2 2 2	0SRB 2X1 FB	SRB 1X4 SO	SRB 1X2	CENT 48	-NULL 4TH-	50794.2	1.
4 2 1 3	1SRB 4X1 FB	SRB 1X4 SO	SRB 1X1	TIT34D 2ND	TIT3 TRAN	50730.0	1.
3 2 2 4	5SRB 3X1 FB	SRB 1X4 SO	SRB 1X2	S-2	S-3	50650.3	1.

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Appendix A-1 Class A LEO Capability (Sheet 3)

CONFIG CODE	STRAP-ON	STAGE 1	STAGE 2	STAGE 3	STAGE 4	PAYLOAD	% PAYLOAD
2 2 1 2	1TIT3 3TH	SRB 1X4 SD	SRB 1X1	CENT 48	TIT3 TRAN	50459.7	1.
4 2 2 1	4SRB 4X1 F5	SRB 1X4 SD	SRB 1X2	CENT D1-T	-NULL 4TH-	50368.3	1.
2 2 1 2	2TIT3 4TH	SRB 1X4 SD	SRB 1X1	CENT 48	IUS 2STAGE	50298.8	1.
2 2 2 3	2TIT3 4TH	SRB 1X4 SD	SRB 1X2	TIT34D 2ND	IUS 2STAGE	50277.2	1.
4 2 1 5	2SRB 4X1 F4	SRB 1X4 SD	SRB 1X1	S-1	IUS 2STAGE	50184.1	1.
2 2 2 3	1TIT3 4TH	SRB 1X4 SD	SRB 1X2	TIT34D 2ND	TIT3 TRAN	50064.9	1.
4 2 1 5	1SRB 4X1 F8	SRB 1X4 SD	SRB 1X1	S-1	TIT3 TRAN	49959.2	1.
2 2 1 4	3TIT3 4TH	SRB 1X4 SD	SRB 1X1	S-2	CENT D1-T	49947.2	1.
4 2 1 4	5SRB 4X1 F5	SRB 1X4 SD	SRB 1X1	S-2	S-3	49945.6	1.
2 2 2 5	2TIT3 4TH	SRB 1X4 SD	SRB 1X2	S-1	IUS 2STAGE	49926.5	1.
3 2 2 1	2SRB 3X1 F5	SRB 1X4 SD	SRB 1X2	CENT D1-T	IUS 2STAGE	49698.4	1.
2 2 1 2	4TIT3 3TH	SRB 1X4 SD	SRB 1X1	CENT 48	-NULL 4TH-	49737.7	1.
4 2 1 1	2SRB 4X1 F4	SRB 1X4 SD	SRB 1X1	CENT D1-T	IUS 2STAGE	49695.3	1.
3 2 2 1	1SRB 3X1 F3	SRB 1X4 SD	SRB 1X2	CENT D1-T	TIT3 TRAN	49671.2	1.
2 2 2 5	1TIT3 3TH	SRB 1X4 SD	SRB 1X2	S-1	TIT3 TRAN	49638.9	1.
4 2 1 1	1SRB 4X1 F[illegible]	SRB 1X4 SD	SRB 1X1	CENT D1-T	TIT3 TRAN	49584.7	1.
2 2 2 1	5TIT3 4TH	SRB 1X4 SD	SRB 1X2	S-2	S-3	48326.8	1.
3 2 2 5	2SRB 3X1 F8	SRB 1X4 SD	SRB 1X2	SRB 1X1	IUS 2STAGE	48514.9	1.
2 2 2 1	2TIT3 3TH	SRB 1X4 SD	SRB 1X2	CENT D1-T	IUS 2STAGE	48525.1	1.
2 2 2 1	1TIT3 4TH	SRB 1X4 SD	SRB 1X2	CENT D1-T	TIT3 TRAN	48316.3	1.
1 2 1 3	5SRB 2X1 F5	SRB 1X4 SD	SRB 1X1	TIT34D 2ND	S-3	47956.7	1.
1 2 1 5	5SRB 2X1 F6	SRB 1X4 SD	SRB 1X1	SRB 1X1	S-3	47784.2	1.
1 2 1 5	5SRB 2X1 F5	SRB 1X4 SD	SRB 1X1	S-1	S-3	47598.8	1.
3 2 2 5	1SRB 3X1 F[illegible]	SRB 1X4 SD	SRB 1X2	SRB 1X1	TIT3 TRAN	47537.6	1.
2 2 2 5	4TIT3 3TH	SRB 1X4 SD	SRB 1X2	SRB 1X1	IUS 2STAGE	47395.6	1.
3 2 2 3	4SRB 3X1 F8	SRB 1X4 SD	SRB 1X2	TIT34D 2ND	-NULL 4TH-	47348.8	1.
1 2 1 2	1SRB 2X1 F[illegible]	SRB 1X4 SD	SRB 1X1	CENT 48	TIT3 TRAN	47268.9	1.
4 2 1 4	3SRB 4X1 F[illegible]	SRB 1X4 SD	SRB 1X1	TIT34D 2ND	-NULL 4TH-	47192.3	1.
4 2 1 5	2SRB 4X1 F[illegible]	SRB 1X4 SD	SRB 1X1	SRB 1X1	IUS 2STAGE	47175.4	1.
1 2 1 2	2SRB 2X1 F[illegible]	SRB 1X4 SD	SRB 1X1	CENT 48	IUS 2STAGE	47071.6	1.
1 2 1 4	3SRB 2X1 F[illegible]	SRB 1X4 SD	SRB 1X1	S-2	CENT D1-T	46980	1.05
4 2 1 1	4SRB 4X1 F[illegible]	SRB 1X4 SD	SRB 1X1	CENT D1-T	-NULL 4TH-	46810.1	1.
1 2 1 2	2SRB 2X1 F[illegible]	SRB 1X4 SD	SRB 1X1	CENT 48	-NULL 4TH-	46737.9	1.
1 2 2 3	2SRB 2X1 F[illegible]	SRB 1X4 SD	SRB 1X2	TIT34D 2ND	IUS 2STAGE	46578.9	1.
3 2 1 3	2SRB 3X1 F5	SRB 1X4 SD	SRB 1X1	TIT34D 2ND	IUS 2STAGE	46528.3	1.
3 2 1 3	1SRB 3X1 F4	SRB 1X4 SD	SRB 1X1	TIT34D 2ND	TIT3 TRAN	45393	1.58
1 2 2 3	1SRB 2X1 F[illegible]	SRB 1X4 SD	SRB 1X2	TIT34D 2ND	TIT3 TRAN	46390.7	1.
2 2 2 5	1TIT3 4TH	SRB 1X4 SD	SRB 1X2	SRB 1X1	TIT3 TRAN	46317.8	1.
1 2 2 5	2SRB 2X1 F8	SRB 1X4 SD	SRB 1X2	S-1	IUS 2STAGE	46172	1.6
3 2 2 5	4SRB 3X1 F[illegible]	SRB 1X4 SD	SRB 1X2	S-1	-NULL 4TH-	46152.4	1.
3 2 2 1	2SRB 3X1 F[illegible]	SRB 1X4 SD	SRB 1X2	CENT D1-T	-NULL 4TH-	46097.8	1.
4 2 1 5	1SRB 4X1 F[illegible]	SRB 1X4 SD	SRB 1X1	SRB 1X1	TIT3 TRAN	46094.5	1.
2 2 2 3	4TIT3 3TH	SRB 1X4 SD	SRB 1X2	TIT34D 2ND	-NULL 4TH-	45996	1.09
1 2 2 5	1SRB 2X1 F[illegible]	SRB 1X4 SD	SRB 1X2	S-1	TIT3 TRAN	45933.8	1.
4 2 2 1	2SRB 4X1 F[illegible]	SRB 1X4 SD	SRB 1X2	S-2	IUS 2STAGE	45978.8	1.
3 1 1 5	4-NULL 5TH-	SRB 1X4	SRB 1X1	SRB 1X1	CENT 48	45856.6	2.
3 2 1 5	2SRB 3X1 F3	SRB 1X4 SD	SRB 1X1	S-1	IUS 2STAGE	45794.8	1.
1 2 2 4	5SRB 2X1 F3	SRB 1X4 SD	SRB 1X2	S-2	S-3	45753.4	1.
3 2 1 4	5SRB 3X1 F5	SRB 1X4 SD	SRB 1X1	S-2	S-3	45719.8	1.
3 2 1 5	1SRB 3X1 F3	SRB 1X4 SD	SRB 1X1	S-1	TIT3 TRAN	45608.7	1.
4 2 1 5	3SRB 4X1 F8	SRB 1X4 SD	SRB 1X1	S-1	-NULL 4TH-	45479.8	1.
3 2 1 1	2SRB 3X1 F8	SRB 1X4 SD	SRB 1X1	CENT D1-T	IUS 2STAGE	45451.3	1.
3 2 1 1	1SRB 3X1 F8	SRB 1X4 SD	SRB 1X1	CENT D1-T	TIT3 TRAN	45384.1	1.
3 1 2 3	3-NULL 5TH-	SRB 1X4	SRB 1X2	TIT34D 2ND	CENT D1-T	45359.3	2.
4 2 2 4	1SRB 4X1 F5	SRB 1X4 SD	SRB 1X2	S-2	TIT3 TRAN	45228.6	1.
3 1 2 5	3-NULL 5TH-	SRB 1X4	SRB 1X2	S-1	CENT D1-T	45199.4	2.
3 1 1 3	4-NULL 5TH-	SRB 1X4	SRB 1X1	TIT34D 2ND	CENT 48	45184.6	2.
3 1 1 5	4-NULL 5TH-	SRB 1X4	SRB 1X1	S-1	CENT 48	44988.3	2.
1 2 2 1	2SRB 2X1 F8	SRB 1X4 SD	SRB 1X2	CENT D1-T	IUS 2STAGE	44961.3	1.
2 2 1 3	2TIT3 4TH	SRB 1X4 SD	SRB 1X1	TIT34D 2ND	IUS 2STAGE	44825.1	1.
2 2 2 5	4TIT3 6TH	SRB 1X4 SD	SRB 1X2	S-1	-NULL 4TH-	44886.5	1.

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Appendix A-1 Class A LEO Capability (Sheet 4)

CONFIG CODE	STRAP-ON	STAGE 1	STAGE 2	STAGE 3	STAGE 4	PAYLOAD	% PAYLOAD
2 2 2 1	2TIT3 [illegible]	SR8 1X4 SD	SR8 1X2	CENT D1-T	-NULL 4TH-	44826	1.47
1 2 2 1	1SR8 2X1 F5	SR8 1X4 SD	SR8 1X2	CENT D1-T	TIT3 TRAN	44794.5	1.5
2 2 1 3	1TIT3 4TH	SR8 1X4 SD	SR8 1X1	TIT34D 2ND	TIT3 TRAN	44712.8	1.5
3 1 2 6	3-NULL 5TH-	SR8 1X4	SR8 1X2	SR8 1X1	CENT D1-T	44411.5	1.8
3 1 2 4	4-NULL 6TH-	SR8 1X4	SR8 1X2	S-2	CENT 4B	44285.9	2.1
2 2 1 5	2TIT3 5TH	SR8 1X4 SD	SR8 1X1	S-1	IUS 2STAGE	44173.1	1.5
2 2 1 4	5TIT3 4TH	SR8 1X4 SD	SR8 1X1	S-2	S-3	44092.3	1.5
2 2 1 5	1TIT3 4TH	SR8 1X4 SD	SR8 1X1	S-1	TIT3 TRAN	43982.1	1.5
2 2 1 1	2TIT3 5TH	SR8 1X4 SD	SR8 1X1	CENT D1-T	IUS 2STAGE	43745.2	1.5
2 2 1 1	1TIT3 4TH	SR8 1X4 SD	SR8 1X1	CENT D1-T	TIT3 TRAN	43695.7	1.5
1 2 2 5	2SR8 2X1 F8	SR8 1X4 SD	SR8 1X2	SR8 1X1	IUS 2STAGE	43359.5	1.3
3 2 1 3	3SR8 3X1 F5	SR8 1X4 SD	SR8 1X1	TIT34D 2ND	-NULL 4TH-	42984.4	1.4
3 2 1 1	1SR8 3X1 F5	SR8 1X4 SD	SR8 1X1	CENT D1-T	-NULL 4TH-	42699.4	1.4
3 2 1 5	2SR8 3X1 F8	SR8 1X4 SD	SR8 1X1	SR8 1X1	IUS 2STAGE	42521.7	1.3
1 2 2 3	1SR8 2X1 F5	SR8 1X4 SD	SR8 1X2	TIT34D 2ND	-NULL 4TH-	42475	1.5
1 2 2 5	1SR8 2X1 F5	SR8 1X4 SD	SR8 1X2	SR8 1X1	TIT3 TRAN	42297.8	1.5
1 2 1 3	2SR8 2X1 F8	SR8 1X4 SD	SR8 1X1	TIT34D 2ND	IUS 2STAGE	41756.5	1.6
1 2 1 3	1SR8 2X1 F5	SR8 1X4 SD	SR8 1X1	TIT34D 2ND	TIT3 TRAN	41679.4	1.5
3 2 2 4	2SR8 3X1 F8	SR8 1X4 SD	SR8 1X2	S-2	IUS 2STAGE	41656.2	1.3
1 2 2 1	2SR8 2X1 F8	SR8 1X4 SD	SR8 1X2	CENT D1-T	-NULL 4TH-	41569.7	1.4
4 2 1 4	2SR8 4X1 F5	SR8 1X4 SD	SR8 1X1	S-2	IUS 2STAGE	41541.8	1.2
3 2 1 5	1SR8 3X1 F5	SR8 1X4 SD	SR8 1X1	SR8 1X1	TIT3 TRAN	41459.5	1.2
2 2 1 3	3TIT3 4TH	SR8 1X4 SD	SR8 1X1	TIT34D 2ND	-NULL 4TH-	41294.8	1.4
2 2 1 1	3TIT3 4TH	SR8 1X4 SD	SR8 1X1	CENT D1-T	-NULL 5TH-	41255	1.5
2 2 1 5	2TIT3 6TH	SR8 1X4 SD	SR8 1X1	SR8 1X1	IUS 2STAGE	41187.2	1.3
1 2 1 4	5SR8 2X1 F5	SR8 1X4 SD	SR8 1X1	S-2	S-3	41138.2	1.5
1 2 1 5	2SR8 2X1 F5	SR8 1X4 SD	SR8 1X1	S-1	IUS 2STAGE	41047.5	1.5
3 2 2 1	1SR8 3X1 F5	SR8 1X4 SD	SR8 1X2	S-2	TIT3 TRAN	41036.5	1.2
4 2 1 4	1SR8 4X1 F5	SR8 1X4 SD	SR8 1X1	S-2	TIT3 TRAN	41031.3	1.2
1 2 1 5	1SR8 2X1 F5	SR8 1X4 SD	SR8 1X1	S-1	TIT3 TRAN	40985.2	1.5
1 2 1 1	2SR8 2X1 F8	SR8 1X4 SD	SR8 1X1	CENT D1-T	IUS 2STAGE	40838.9	1.5
1 2 1 1	1SR8 2X1 F5	SR8 1X4 SD	SR8 1X1	CENT D1-T	TIT3 TRAN	40672.1	1.5
2 2 2 4	2TIT3 4TH	SR8 1X4 SD	SR8 1X2	S-2	IUS 2STAGE	40429.1	1.3
3 1 1 4	4-NULL 5TH-	SR8 1X4	SR8 1X1	TIT34D 2ND	CENT D1-T	40163.5	2.2
2 2 1 5	1TIT3 4TH	SR8 1X4 SD	SR8 1X1	SR8 1X1	TIT3 TRAN	40126.1	1.2
2 2 2 4	1TIT3 4TH	SR8 1X4 SD	SR8 1X2	S-2	TIT3 TRAN	39798.2	1.2
3 1 1 5	3-NULL 5TH-	SR8 1X4	SR8 1X1	S-1	CENT D1-T	39774.7	2.1
3 1 1 4	4-NULL 5TH-	SR8 1X4	SR8 1X1	S-2	CENT 4B	39192.4	2.2
3 1 2 4	5-NULL 5TH-	SR8 1X4	SR8 1X2	TIT34D 2ND	S-3	38767.7	1.8
3 1 2 5	5-NULL 5TH-	SR8 1X4	SR8 1X2	S-1	S-3	38698.1	1.9
1 2 1 1	4SR8 2X1 F5	SR8 1X4 SD	SR8 1X1	CENT D1-T	-NULL 4TH-	38662.2	1.5
3 1 1 5	3-NULL 4TH-	SR8 1X4	SR8 1X1	SR8 1X1	CENT D1-T	38581.2	1.8
1 2 1 4	2SR8 2X1 F5	SR8 1X4 SD	SR8 1X1	TIT34D 2ND	-NULL 4TH-	38423.8	1.5
3 1 2 4	3-NULL 4TH-	SR8 1X4	SR8 1X2	S-2	CENT D1-T	37898.5	1.8
3 2 1 4	2SR8 3X1 F5	SR8 1X4 SD	SR8 1X1	S-2	IUS 2STAGE	37665.9	1.2
1 2 1 5	2SR8 2X1 F5	SR8 1X4 SD	SR8 1X1	SR8 1X1	IUS 2STAGE	37616.8	1.3
3 1 2 2	1-NULL 4TH-	SR8 1X4	SR8 1X2	CENT 4B	TIT3 TRAN	37564.6	1.8
3 1 2 2	2-NULL 4TH-	SR8 1X4	SR8 1X2	CENT 4B	IUS 2STAGE	37367.6	1.8
3 2 1 4	1SR8 3X1 F5	SR8 1X4 SD	SR8 1X1	S-2	TIT3 TRAN	37204.8	1.2
1 2 2 4	2SR8 2X1 F8	SR8 1X4 SD	SR8 1X2	S-2	IUS 2STAGE	37169.4	1.3
4 2 2 5	3SR8 4X1 F8	SR8 1X4 SD	SR8 1X2	SR8 1X1	-NULL 4TH-	37023.8	.95
3 1 2 2	3-NULL 4TH-	SR8 1X4	SR8 1X2	CENT 4B	-NULL 4TH-	36986.7	1.9
4 2 2 4	3SR8 4X1 F8	SR8 1X4 SD	SR8 1X2	S-2	-NULL 4TH-	36959.9	1.0
1 2 2 4	1SR8 2X1 F5	SR8 1X4 SD	SR8 1X2	S-2	TIT3 TRAN	36627	1.3
1 2 1 5	1SR8 2X1 F8	SR8 1X4 SD	SR8 1X1	SR8 1X1	TIT3 TRAN	35583.3	1.2
2 2 1 4	2TIT3 4TH	SR8 1X4 SD	SR8 1X1	S-2	IUS 2STAGE	35111.2	1.3
2 2 1 4	1TIT3 4TH	SR8 1X4 SD	SR8 1X1	S-2	TIT3 TRAN	34659.6	1.2
4 2 1 4	4SR8 4X1 F8	SR8 1X4 SD	SR8 1X1	S-2	-NULL 4TH-	33943.3	1.0
3 1 1 5	5-NULL 4TH-	SR8 1X4	SR8 1X1	SR8 1X1	S-3	33761.3	1.5
3 1 1 4	3-NULL 5TH-	SR8 1X4	SR8 1X1	S-2	CENT D1-T	33669.5	1.9
3 1 1 3	5-NULL 4TH-	SR8 1X4	SR8 1X1	TIT34D 2ND	S-3	33587.5	1.9

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Appendix A1 Class A LEO Capability (Sheet 5)

CONFIG CODE	STRAP-ON	STAGE 1	STAGE 2	STAGE 3	STAGE 4	PAYLOAD	% PAYLOAD
1 2 1 4	2SRB 2X1 FB	SRB 1X4 SO	SRB 1X1	S-2	-IUS 2STAGE	33486.1	1.33
2 1 1 5	5-NULL 4TH-	SRB 1X4	SRB 1X1	S-1	S-3	33353.6	1.82
2 1 1 2	4-NULL 4TH-	SRB 1X4	SRB 1X1	CENT 4B	-NULL 4TH-	33139.6	1.91
1 2 1 4	1SRB 2X1 FB	SRB 1X4 SO	SRB 1X1	S-2	TIT3 TRAN	33081.7	1.31
3 2 2 4	0SRB 3X1 FB	SRB 1X4 SO	SRB 1X2	S-2	-NULL 4TH-	33004.1	1.84
2 1 1 2	1-NULL 4TH-	SRB 1X4	SRB 1X1	CENT 4B	TIT3 TRAN	32969.3	1.88
2 1 2 3	2-NULL 4TH-	SRB 1X4	SRB 1X2	TIT34D 2ND	IUS 2STAGE	32884.9	1.58
2 1 2 3	1-NULL 4TH-	SRB 1X4	SRB 1X2	TIT34D 2ND	TIT3 TRAN	32740.3	1.58
2 1 1 2	2-NULL 4TH-	SRB 1X4	SRB 1X1	CENT 4B	IUS 2STAGE	32665.1	1.85
2 1 2 4	5-NULL 4TH-	SRB 1X4	SRB 1X2	S-2	S-3	32491.7	1.57
2 1 2 5	2-NULL 4TH-	SRB 1X4	SRB 1X2	S-1	IUS 2STAGE	32475.5	1.54
2 1 2 5	1-NULL 4TH-	SRB 1X4	SRB 1X2	S-1	TIT3 TRAN	32341.2	1.54
2 2 2 4	2TIT3 4TH	SRB 1X4 SO	SRB 1X2	S-2	-NULL 4TH-	31847.4	1.85
2 1 2 1	2-NULL 4TH-	SRB 1X4	SRB 1X2	CENT D1-T	IUS 2STAGE	31586.9	1.55
2 1 2 1	1-NULL 4TH-	SRB 1X4	SRB 1X2	CENT D1-T	TIT3 TRAN	31573.9	1.55
3 2 2 5	2SRB 3X1 FB	SRB 1X4 SO	SRB 1X2	SRB 1X1	-NULL 4TH-	31085	.89 .5
3 2 1 4	0SRB 3X1 FB	SRB 1X4 SO	SRB 1X1	S-2	-NULL 4TH-	30332.3	1.25
2 1 2 5	2-NULL 4TH-	SRB 1X4	SRB 1X2	SRB 1X1	IUS 2STAGE	29824.2	1.26
2 2 2 5	2TIT3 4TH	SRB 1X4 SO	SRB 1X2	SRB 1X1	-NULL 4TH-	29589.9	.88
2 1 2 1	3-NULL 4TH-	SRB 1X4	SRB 1X2	CENT D1-T	-NULL 4TH-	29427.4	1.47
4 2 1 5	2SRB 4X1 FB	SRB 1X4 SO	SRB 1X1	SRB 1X1	-NULL 4TH-	29295.3	.82
2 1 2 3	4-NULL 4TH-	SRB 1X4	SRB 1X2	TIT34D 2ND	-NULL 4TH-	29260.4	1.44
2 1 2 5	1-NULL 4TH-	SRB 1X4	SRB 1X2	SRB 1X1	TIT3 TRAN	28865.3	1.22
1 2 2 4	2SRB 2X1 FB	SRB 1X4 SO	SRB 1X2	S-2	-NULL 4TH-	28852.8	1.84
2 2 1 4	2TIT3 4TH	SRB 1X4 SO	SRB 1X1	S-2	-NULL 4TH-	28827.5	1.85
2 1 1 3	1-NULL 4TH-	SRB 1X4	SRB 1X1	TIT34D 2ND	TIT3 TRAN	28336.4	1.6
2 1 1 3	2-NULL 4TH-	SRB 1X4	SRB 1X1	TIT34D 2ND	IUS 2STAGE	28330.8	1.5
2 1 1 4	5-NULL 4TH-	SRB 1X4	SRB 1X1	S-2	S-3	28169.9	1.59
2 1 1 1	1-NULL 4TH-	SRB 1X4	SRB 1X1	CENT D1-T	TIT3 TRAN	27832.9	1.51
2 1 1 5	2-NULL 4TH-	SRB 1X4	SRB 1X1	S-1	IUS 2STAGE	27710.5	1.54
2 1 1 1	2-NULL 4TH-	SRB 1X4	SRB 1X1	CENT D1-T	IUS 2STAGE	27783.0	1.59
2 1 1 5	1-NULL 4TH-	SRB 1X4	SRB 1X1	S-1	TIT3 TRAN	27664.2	1.54
2 1 1 1	4-NULL 4TH-	SRB 1X4	SRB 1X1	CENT D1-T	-NULL 4TH-	25668.3	1.55
1 2 1 4	0SRB 2X1 FB	SRB 1X4 SO	SRB 1X1	S-2	-NULL 4TH-	25457.9	1.36
2 1 1 3	3-NULL 4TH-	SRB 1X4	SRB 1X1	TIT34D 2ND	-NULL 4TH-	25443.3	1.46
2 1 2 4	2-NULL 4TH-	SRB 1X4	SRB 1X2	S-2	IUS 2STAGE	25280.9	1.24

Appendix A2 Class A GEO Capability (Sheet 1)

CONFIG CODE	STRAP-ON	STAGE 1	STAGE 2	STAGE 3	STAGE 4	PAYLOAD	% PAYLOAD
4 2 2 3	4SRB 4X1 F8	SRB 1X4 SD	SRB 1X2	TIT34D 2ND	CENT 48	15753.2	.43
4 2 2 5	4SRB 4X1 F8	SRB 1X4 SD	SRB 1X2	S-1	CENT 48	15549.0	.42
3 2 2 3	4SRB 3X1 F8	SRB 1X4 SD	SRB 1X2	TIT34D 2ND	CENT 48	14683.5	.45
4 2 1 3	4SRB 4X1 F8	SRB 1X4 SD	SRB 1X1	TIT34D 2ND	CENT 48	14491.5	.43
3 2 2 5	4SRB 3X1 F8	SRB 1X4 SD	SRB 1X2	S-1	CENT 48	14429.1	.44
2 2 2 3	4TIT3 8TH	SRB 1X4 SD	SRB 1X2	TIT34D 2ND	CENT 48	14261.5	.46
4 2 2 6	4SRB 4X1 F8	SRB 1X4 SD	SRB 1X2	SRB 1X1	CENT 48	14198.9	.35
4 2 1 5	4SRB 4X1 F8	SRB 1X4 SD	SRB 1X1	S-1	CENT 48	14195	.42
2 2 2 5	4TIT3 8TH	SRB 1X4 SD	SRB 1X2	S-1	CENT 48	14078.1	.45
4 2 2 3	3SRB 4X1 F8	SRB 1X4 SD	SRB 1X2	TIT34D 2ND	CENT D1-T	13887	.38
4 2 2 5	3SRB 4X1 F8	SRB 1X4 SD	SRB 1X2	S-1	CENT D1-T	13585.3	.37
3 2 1 3	4SRB 3X1 F8	SRB 1X4 SD	SRB 1X1	TIT34D 2ND	CENT 48	13386.7	.45
1 2 2 3	4SRB 2X1 F8	SRB 1X4 SD	SRB 1X2	TIT34D 2ND	CENT 48	13339.5	.47
1 2 2 5	4SRB 2X1 F8	SRB 1X4 SD	SRB 1X2	S-1	CENT 48	13159.1	.45
3 2 2 6	4SRB 3X1 F8	SRB 1X4 SD	SRB 1X2	SRB 1X1	CENT 48	13123.4	.37
3 2 1 5	4SRB 3X1 F8	SRB 1X4 SD	SRB 1X1	S-1	CENT 48	13142.7	.44
2 2 1 3	4TIT3 8TH	SRB 1X4 SD	SRB 1X1	TIT34D 2ND	CENT 48	12944.9	.45
4 2 2 4	4SRB 4X1 F8	SRB 1X4 SD	SRB 1X2	S-2	CENT 48	12875.9	.36
2 2 2 6	4TIT3 8TH	SRB 1X4 SD	SRB 1X2	SRB 1X1	CENT 48	12855.5	.38
3 2 2 3	3SRB 3X1 F8	SRB 1X4 SD	SRB 1X2	TIT34D 2ND	CENT D1-T	12847.6	.4
4 2 1 5	4SRB 4X1 F8	SRB 1X4 SD	SRB 1X1	SRB 1X1	CENT 48	12804.5	.35
4 2 1 3	3SRB 4X1 F8	SRB 1X4 SD	SRB 1X1	TIT34D 2ND	CENT D1-T	12787.8	.38
2 2 1 5	4TIT3 8TH	SRB 1X4 SD	SRB 1X1	S-1	CENT 48	12683.3	.44
3 2 2 5	3SRB 3X1 F8	SRB 1X4 SD	SRB 1X2	S-1	CENT D1-T	12518.5	.36
2 2 2 3	3TIT3 8TH	SRB 1X4 SD	SRB 1X2	TIT34D 2ND	CENT D1-T	12585	.4
4 2 1 5	3SRB 4X1 F8	SRB 1X4 SD	SRB 1X1	S-1	CENT D1-T	12398.7	.37
2 2 2 5	3TIT3 8TH	SRB 1X4 SD	SRB 1X2	S-1	CENT D1-T	12226.1	.39
1 2 1 3	3SRB 2X1 F8	SRB 1X4 SD	SRB 1X1	TIT34D 2ND	CENT 48	12156.9	.47
1 2 2 6	3SRB 2X1 F8	SRB 1X4 SD	SRB 1X2	SRB 1X1	CENT 48	11962	.35
4 2 1 4	3SRB 4X1 F8	SRB 1X4 SD	SRB 1X1	S-2	CENT 48	11945.5	.36
1 2 1 5	3SRB 2X1 F8	SRB 1X4 SD	SRB 1X1	S-1	CENT 48	11883.5	.46
3 2 2 4	3SRB 3X1 F8	SRB 1X4 SD	SRB 1X2	S-2	CENT 48	11851.8	.37
3 2 1 3	3SRB 3X1 F8	SRB 1X4 SD	SRB 1X1	TIT34D 2ND	CENT D1-T	11826.0	.4
3 2 1 5	4SRB 3X1 F8	SRB 1X4 SD	SRB 1X1	SRB 1X1	CENT 48	11776	.36
1 2 2 3	4SRB 2X1 F8	SRB 1X4 SD	SRB 1X2	TIT34D 2ND	CENT D1-T	11716.7	.41
2 2 2 4	4TIT3 8TH	SRB 1X4 SD	SRB 1X2	S-2	CENT 48	11553.3	.37
2 2 1 5	4TIT3 8TH	SRB 1X4 SD	SRB 1X1	SRB 1X1	CENT 48	11463	.37
1 2 2 5	3SRB 2X1 F8	SRB 1X4 SD	SRB 1X2	S-1	CENT D1-T	11437.4	.4
3 2 1 5	3SRB 3X1 F8	SRB 1X4 SD	SRB 1X1	S-1	CENT D1-T	11437	.38
2 2 1 3	3TIT3 8TH	SRB 1X4 SD	SRB 1X1	TIT34D 2ND	CENT D1-T	11434.7	.41
4 2 2 5	3SRB 4X1 F8	SRB 1X4 SD	SRB 1X2	SRB 1X1	CENT D1-T	11240.3	.29
2 2 1 5	3TIT3 8TH	SRB 1X4 SD	SRB 1X1	S-1	CENT D1-T	11065.2	.39
3 2 1 4	4SRB 3X1 F8	SRB 1X4 SD	SRB 1X1	S-2	CENT 48	10926.1	.37
4 2 2 4	3SRB 4X1 F8	SRB 1X4 SD	SRB 1X2	S-2	CENT D1-T	10792.3	.3
1 2 1 3	3SRB 2X1 F8	SRB 1X4 SD	SRB 1X1	TIT34D 2ND	CENT D1-T	10755.9	.42
1 2 2 4	4SRB 2X1 F8	SRB 1X4 SD	SRB 1X2	S-2	CENT 48	10746.9	.38
1 2 1 5	4SRB 2X1 F8	SRB 1X4 SD	SRB 1X1	SRB 1X1	CENT 48	10630.3	.37
2 2 1 4	3TIT3 8TH	SRB 1X4 SD	SRB 1X1	S-2	CENT 48	10521.2	.38
1 2 1 5	3SRB 2X1 F8	SRB 1X4 SD	SRB 1X1	S-1	CENT D1-T	10385.3	.4
3 2 2 5	3SRB 3X1 F8	SRB 1X4 SD	SRB 1X2	SRB 1X1	CENT D1-T	10359.5	.29
2 2 2 6	3TIT3 8TH	SRB 1X4 SD	SRB 1X2	SRB 1X1	CENT D1-T	10130.7	.3
4 2 1 5	3SRB 4X1 F8	SRB 1X4 SD	SRB 1X1	SRB 1X1	CENT D1-T	10095.3	.28
4 2 1 4	3SRB 4X1 F8	SRB 1X4 SD	SRB 1X1	S-2	CENT D1-T	10081.3	.3
3 2 2 4	3SRB 3X1 F8	SRB 1X4 SD	SRB 1X2	S-2	CENT D1-T	9936.38	.31
1 2 1 4	4SRB 2X1 F8	SRB 1X4 SD	SRB 1X1	S-2	CENT 48	9832.75	.39
2 2 2 4	3TIT3 8TH	SRB 1X4 SD	SRB 1X2	S-2	CENT D1-T	9675.19	.31
[illegible] 1 2 3	4-NULL 8TH-	SRB 1X4	SRB 1X2	TIT34D 2ND	CENT 48	9675.38	.45
4 2 2 2	3SRB 4X1 F8	SRB 1X4 SD	SRB 1X2	CENT 48	4-NULL 4TH-	9623.16	.27
[illegible] 1 2 5	4-NULL 8TH-	SRB 1X4	SRB 1X2	S-1	CENT 48	9557.39	.45
1 2 2 5	3SRB 2X1 F8	SRB 1X4 SD	SRB 1X2	SRB 1X1	CENT D1-T	9417.59	.3

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Appendix A-2 Class A GEO Capability (Sheet 2)

CONFIG CODE	STRAP-ON	STAGE 1	STAGE 2	STAGE 3	STAGE 4	PAYLOAD	% PAYLOAD
3 2 1 4	3SRB 3X1 FB	SRB 1X4 SD	SRB 1X1	S-2	CENT D1-T	9263.83	.3
3 2 1 5	3SRB 3X1 FB	SRB 1X4 SD	SRB 1X1	SRB 1X1	CENT D1-T	9254.94	.2
4 2 1 2	3SRB 4X1 FB	SRB 1X4 SD	SRB 1X1	CENT 48	-NULL 4TH-	9391.83	.2
1 2 2 4	3SRB 2X1 FB	SRB 1X4 SD	SRB 1X2	S-2	CENT D1-T	9046.90	.3
2 2 1 5	3TIT3 0TH	SRB 1X4 SD	SRB 1X1	SRB 1X1	CENT D1-T	9002.56	.2
2 2 1 4	3TIT3 0TH	SRB 1X4 SD	SRB 1X1	S-2	CENT D1-T	8912.34	.3
3 2 2 2	0SRB 3X1 FB	SRB 1X4 SD	SRB 1X2	CENT 48	-NULL 4TH-	8734.81	.2
0 1 2 5	3-NULL 0TH-	SRB 1X4	SRB 1X2	SRB 1X1	CENT 48	8726.72	.3
4 2 2 2	1SRB 2X1 FB	SRB 1X4 SD	SRB 1X2	CENT 48	TIT3 TRAN	8680.19	.2
0 1 2 3	3-NULL 0TH-	SRB 1X4	SRB 1X2	TIT34D 2ND	CENT D1-T	8551.26	.41
2 2 2 2	0TIT3 4TH	SRB 1X4 SD	SRB 1X2	CENT 48	-NULL 4TH-	8461.94	.2
0 1 1 3	3-NULL 0TH-	SRB 1X4	SRB 1X1	TIT34D 2ND	CENT 48	8198.25	.4
1 2 1 4	3SRB 2X1 FB	SRB 1X4 SD	SRB 1X1	S-2	CENT D1-T	8146.66	.3
1 2 1 5	3SRB 2X1 FB	SRB 1X4 SD	SRB 1X1	SRB 1X1	CENT D1-T	8339	.2
3 2 1 2	0SRB 3X1 FB	SRB 1X4 SD	SRB 1X1	CENT 48	-NULL 4TH-	8243	.23
0 1 1 5	3-NULL 0TH-	SRB 1X4	SRB 1X1	S-1	CENT 48	8199.22	.4
4 2 2 2	2SRB 4X1 FB	SRB 1X4 SD	SRB 1X2	CENT 48	IUS 2STAGE	8147.34	.2
4 2 1 2	1SRB 4X1 FB	SRB 1X4 SD	SRB 1X1	CENT 48	TIT3 TRAN	7954	.24
2 2 1 2	0TIT3 4TH	SRB 1X4 SD	SRB 1X1	CENT 48	-NULL 4TH-	7908.56	.2
3 2 2 2	1SRB 3X1 FB	SRB 1X4 SD	SRB 1X2	CENT 48	TIT3 TRAN	7121.47	.24
1 2 2 2	2SRB 2X1 FB	SRB 1X4 SD	SRB 1X2	CENT 48	-NULL 4TH-	7761.39	.26
2 2 2 2	1TIT3 0TH	SRB 1X4 SD	SRB 1X2	CENT 48	TIT3 TRAN	7555.81	.24
0 1 1 3	3-NULL 0TH-	SRB 1X4	SRB 1X1	TIT34D 2ND	CENT D1-T	7511.56	.4
3 1 2 4	3-NULL 0TH-	SRB 1X4	SRB 1X2	S-2	CENT 48	7509.5	.36
4 2 1 2	2SRB 4X1 FB	SRB 1X4 SD	SRB 1X1	CENT 48	IUS 2STAGE	7389.72	.22
0 1 1 5	3-NULL 0TH-	SRB 1X4	SRB 1X1	SRB 1X1	CENT 48	7378.75	.35
1 2 1 2	2SRB 2X1 FB	SRB 1X4 SD	SRB 1X1	CENT 48	-NULL 4TH-	7293.59	.25
3 2 2 2	2SRB 3X1 FB	SRB 1X4 SD	SRB 1X2	CENT 48	IUS 2STAGE	7287.59	.22
3 2 1 2	1SRB 3X1 FB	SRB 1X4 SD	SRB 1X1	CENT 48	TIT3 TRAN	7128.97	.24
2 2 2 2	2TIT3 4TH	SRB 1X4 SD	SRB 1X2	CENT 48	IUS 2STAGE	7115.20	.22
4 2 1 1	1SRB 4X1 FB	SRB 1X4 SD	SRB 1X1	CENT D1-T	-NULL 4TH-	6965.53	.21
1 2 2 2	1SRB 2X1 FB	SRB 1X4 SD	SRB 1X2	CENT 48	TIT3 TRAN	6867.30	.24
0 1 2 5	3-NULL 0TH-	SRB 1X4	SRB 1X2	SRB 1X1	CENT D1-T	6798.75	.29
2 2 1 2	1TIT3 0TH	SRB 1X4 SD	SRB 1X1	CENT 48	TIT3 TRAN	6782.59	.24
3 2 1 2	2SRB 3X1 FB	SRB 1X4 SD	SRB 1X1	CENT 48	IUS 2STAGE	6556.34	.22
4 2 2 1	1SRB 4X1 FB	SRB 1X4 SD	SRB 1X2	CENT D1-T	TIT3 TRAN	6537.22	.18
4 2 2 3	1SRB 4X1 FB	SRB 1X4 SD	SRB 1X2	TIT34D 2ND	TIT3 TRAN	6527.56	.18
0 1 1 4	3-NULL 0TH-	SRB 1X4	SRB 1X1	S-2	CENT 48	6388.59	.37
1 2 2 2	2SRB 2X1 FB	SRB 1X4 SD	SRB 1X2	CENT 48	IUS 2STAGE	6339.22	.22
0 1 2 4	3-NULL 0TH-	SRB 1X4	SRB 1X2	S-2	CENT D1-T	6326.83	.31
3 2 1 1	0SRB 3X1 FB	SRB 1X4 SD	SRB 1X1	CENT D1-T	-NULL 4TH-	6302.13	.22
1 2 1 2	1SRB 2X1 FB	SRB 1X4 SD	SRB 1X1	CENT 48	TIT3 TRAN	6217.13	.24
2 2 1 2	2TIT3 0TH	SRB 1X4 SD	SRB 1X1	CENT 48	IUS 2STAGE	6207.59	.22
4 2 2 3	2SRB 4X1 FB	SRB 1X4 SD	SRB 1X2	TIT34D 2ND	IUS 2STAGE	6164.5	.17
4 2 2 1	2SRB 4X1 FB	SRB 1X4 SD	SRB 1X2	CENT D1-T	IUS 2STAGE	6067.75	.17
4 2 1 1	1SRB 4X1 FB	SRB 1X4 SD	SRB 1X1	CENT D1-T	TIT3 TRAN	6059.5	.18
2 2 1 1	0TIT3 0TH	SRB 1X4 SD	SRB 1X1	CENT D1-T	-NULL 4TH-	5999.69	.22
4 2 1 3	1SRB 4X1 FB	SRB 1X4 SD	SRB 1X1	TIT34D 2ND	TIT3 TRAN	5935.53	.17
3 2 2 1	1SRB 3X1 FB	SRB 1X4 SD	SRB 1X2	CENT D1-T	TIT3 TRAN	5911.91	.18
3 2 2 3	1SRB 3X1 FB	SRB 1X4 SD	SRB 1X2	TIT34D 2ND	TIT3 TRAN	5789.19	.18
0 1 1 5	3-NULL 0TH-	SRB 1X4	SRB 1X1	SRB 1X1	CENT D1-T	5725.34	.20
1 2 1 2	2SRB 2X1 FB	SRB 1X4 SD	SRB 1X1	CENT 48	IUS 2STAGE	5637.44	.22
2 2 2 1	1TIT3 0TH	SRB 1X4 SD	SRB 1X2	CENT D1-T	TIT3 TRAN	5586.34	.18
0 1 1 4	3-NULL 0TH-	SRB 1X4	SRB 1X1	S-2	CENT D1-T	5567.31	.32
4 2 1 1	2SRB 4X1 FB	SRB 1X4 SD	SRB 1X1	CENT D1-T	IUS 2STAGE	5566.97	.17
2 2 2 3	1TIT3 0TH	SRB 1X4 SD	SRB 1X2	TIT34D 2ND	TIT3 TRAN	5564.88	.18
1 2 1 1	0SRB 2X1 FB	SRB 1X4 SD	SRB 1X1	CENT D1-T	-NULL 4TH-	5559.53	.22
4 2 1 3	2SRB 4X1 FB	SRB 1X4 SD	SRB 1X1	TIT34D 2ND	IUS 2STAGE	5437.78	.16
3 2 2 3	2SRB 3X1 FB	SRB 1X4 SD	SRB 1X2	TIT34D 2ND	IUS 2STAGE	5408.78	.16
3 2 1 1	1SRB 3X1 FB	SRB 1X4 SD	SRB 1X1	CENT D1-T	TIT3 TRAN	5356.94	.18
3 2 2 1	2SRB 3X1 FB	SRB 1X4 SD	SRB 1X2	CENT D1-T	IUS 2STAGE	5348.25	.16

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Appendix A2 Class A GEO Capability (Sheet 3)

CONFIG CODE	STRAP-ON	STAGE 1	STAGE 2	STAGE 3	STAGE 4	PAYLOAD	% PAYLOAD
2 2 2 3	2TIT3 4TH	SRB 1X4 SD	SRB 1X2	TIT34D 2ND	IUS 2STAGE	5101.25	.16
3 2 1 3	1SRB 3X1 FB	SRB 1X4 SD	SRB 1X1	TIT34D 2ND	TIT3 TRAN	5133.31	.17
2 2 2 1	2TIT3 4TH	SRB 1X4 SD	SRB 1X2	CENT D1-T	IUS 2STAGE	5117.66	.16
2 2 1 1	1TIT3 4TH	SRB 1X4 SD	SRB 1X1	CENT D1-T	TIT3 TRAN	5050.59	.18
1 2 2 1	1SRB 2X1 FB	SRB 1X4 SD	SRB 1X2	CENT D1-T	TIT3 TRAN	5023.56	.18
9 1 2 2	4-NULL 4TH-	SRB 1X4	SRB 1X2	CENT 4B	-NULL 4TH-	5014.77	.25

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Appendix A-3 Class B LEO Capability

CONFIG CODE	STRAP-ON	STAGE 1	STAGE 2	STAGE 3	STAGE 4	PAYLOAD	% PAYLOAD
2 4 5	4-NULL 8TH-	SRB 2X4	SRB 1X5	SRB 1X1	CENT 48	84846.3	1.85
3 1 5	4-NULL 8TH-	SRB 2X5	SRB 1X2	SRB 1X1	CENT 48	80367.5	1.86
2 3 5	4-NULL 8TH-	SRB 2X4	SRB 1X4	SRB 1X1	CENT 48	79713.4	1.86
2 4 5	4-NULL 8TH-	SRB 2X4	SRB 1X5	S-1	CENT 48	78804.3	1.81
3 2 5	4-NULL 8TH-	SRB 2X5	SRB 1X3	S-1	CENT 48	77570.3	1.8
3 1 5	4-NULL 8TH-	SRB 2X5	SRB 1X2	S-1	CENT 48	77096.7	1.91
3 1 3	4-NULL 8TH-	SRB 2X5	SRB 1X2	TIT34D 2ND	CENT 48	76900.3	1.92
2 4 3	4-NULL 8TH-	SRB 2X4	SRB 1X5	TIT34D 2ND	CENT 48	76834.1	1.8
3 2 3	4-NULL 8TH-	SRB 2X5	SRB 1X3	TIT34D 2ND	CENT 48	76779.5	1.79
2 4 5	3-NULL 8TH-	SRB 2X4	SRB 1X5	SRB 1X1	CENT D1-T	75805.7	1.64
1 1 5	4-NULL 8TH-	SRB 2X3	SRB 1X5	SRB 1X1	CENT 48	74752.0	1.87
2 3 5	4-NULL 8TH-	SRB 2X4	SRB 1X4	S-1	CENT 48	73954.3	1.84
2 2 5	4-NULL 8TH-	SRB 2X4	SRB 1X3	SRB 1X1	CENT 48	73742	1.84
2 3 3	4-NULL 8TH-	SRB 2X4	SRB 1X4	TIT34D 2ND	CENT 48	73030.3	1.83
2 1 5	4-NULL 8TH-	SRB 2X4	SRB 1X2	SRB 1X1	CENT 48	70924.4	1.91
3 1 5	3-NULL 8TH-	SRB 2X5	SRB 1X2	SRB 1X1	CENT D1-T	70067.9	1.95
2 3 5	3-NULL 8TH-	SRB 2X4	SRB 1X4	SRB 1X1	CENT D1-T	70133.3	1.64
1 3 5	4-NULL 8TH-	SRB 2X3	SRB 1X4	SRB 1X1	CENT 48	69720.3	1.88
2 4 5	3-NULL 8TH-	SRB 2X4	SRB 1X5	S-1	CENT D1-T	69583.3	1.62
3 2 5	3-NULL 8TH-	SRB 2X5	SRB 1X3	S-1	CENT D1-T	69444.6	1.62
3 1 5	3-NULL 8TH-	SRB 2X5	SRB 1X2	S-1	CENT D1-T	69421.3	1.73
2 4 5	5-NULL 8TH-	SRB 2X4	SRB 1X5	SRB 1X1	S-3	69301.0	1.51
3 1 3	3-NULL 8TH-	SRB 2X5	SRB 1X2	TIT34D 2ND	CENT D1-T	69307.3	1.74
2 2 5	4-NULL 8TH-	SRB 2X4	SRB 1X3	S-1	CENT 48	68798.0	1.85
3 2 3	3-NULL 8TH-	SRB 2X5	SRB 1X3	TIT34D 2ND	CENT D1-T	68657.9	1.61
1 1 5	4-NULL 8TH-	SRB 2X3	SRB 1X5	S-1	CENT 48	68529.4	1.84
2 4 3	3-NULL 8TH-	SRB 2X4	SRB 1X5	TIT34D 2ND	CENT D1-T	68359.9	1.61
2 1 5	4-NULL 8TH-	SRB 2X4	SRB 1X2	S-1	CENT 48	68152.7	1.99
2 2 3	4-NULL 8TH-	SRB 2X4	SRB 1X3	TIT34D 2ND	CENT 48	68045.7	1.84
2 1 3	4-NULL 8TH-	SRB 2X4	SRB 1X2	TIT34D 2ND	CENT 48	67977.1	1.99
3 1 4	4-NULL 8TH-	SRB 2X5	SRB 1X2	S-2	CENT 48	67056.0	1.71
1 1 3	4-NULL 8TH-	SRB 2X3	SRB 1X5	TIT34D 2ND	CENT 48	67416.2	1.93
3 2 4	4-NULL 8TH-	SRB 2X5	SRB 1X3	S-2	CENT 48	66711.4	1.57
2 4 4	4-NULL 8TH-	SRB 2X4	SRB 1X5	S-2	CENT 48	66217.3	1.56
2 3 5	3-NULL 8TH-	SRB 2X4	SRB 1X4	S-1	CENT D1-T	65948.9	1.55
1 4 5	3-NULL 8TH-	SRB 2X3	SRB 1X5	SRB 1X1	CENT D1-T	65369.5	1.95
3 1 5	5-NULL 8TH-	SRB 2X5	SRB 1X2	SRB 1X1	S-3	65238.1	1.52
2 3 3	3-NULL 8TH-	SRB 2X4	SRB 1X4	TIT34D 2ND	CENT D1-T	64998.4	1.64
2 3 5	5-NULL 8TH-	SRB 2X4	SRB 1X4	SRB 1X1	S-3	64592.8	1.51
1 3 5	4-NULL 8TH-	SRB 2X3	SRB 1X4	S-1	CENT 48	64525.0	1.89
2 2 5	3-NULL 8TH-	SRB 2X4	SRB 1X3	SRB 1X1	CENT D1-T	64450.1	1.52
1 2 5	4-NULL 8TH-	SRB 2X3	SRB 1X3	SRB 1X1	CENT 48	63950.3	1.99
1 3 3	4-NULL 8TH-	[illegible]	SRB 1X4	TIT34D 2ND	CENT 48	63630.5	1.98
2 4 5	5-NULL 8TH-	SRB 2X4	SRB 1X5	S-1	S-3	63249.5	1.47
2 3 4	4-NULL 8TH-	SRB 2X4	SRB 1X4	S-2	CENT 48	63030.4	1.5
3 2 5	5-NULL 8TH-	SRB 2X5	SRB 1X3	S-1	S-3	62898.1	1.45
3 1 5	5-NULL 8TH-	SRB 2X5	SRB 1X2	S-1	S-3	62683	1.55
3 1 3	5-NULL 8TH-	SRB 2X5	SRB 1X2	TIT34D 2ND	S-3	62460.0	1.56
3 2 3	5-NULL 8TH-	SRB 2X5	SRB 1X3	TIT34D 2ND	S-3	62173.4	1.45
2 4 3	5-NULL 8TH-	SRB 2X4	SRB 1X5	TIT34D 2ND	S-3	62124.6	1.45
2 1 6	3-NULL 8TH-	SRB 2X4	SRB 1X2	SRB 1X1	CENT D1-T	61886.5	1.60
2 2 5	3-NULL 8TH-	SRB 2X4	SRB 1X3	S-1	CENT D1-T	61222.6	1.65
2 1 5	3-NULL 8TH-	SRB 2X4	SRB 1X2	S-1	CENT D1-T	61017.0	1.79
[illegible] 1 6	4-NULL 8TH-	SRB 2X3	SRB 1X2	SRB 1X1	CENT 48	60997.6	1.96
2 1 3	3-NULL 8TH-	SRB 2X4	SRB 1X2	TIT34D 2ND	CENT D1-T	60939.0	1.8
[illegible] 5	3-NULL 8TH-	SRB 2X3	SRB 1X5	S-1	CENT D1-T	60725.9	1.64
[illegible] 6	3-NULL 8TH-	SRB 2X3	SRB 1X4	SRB 1X1	CENT D1-T	60622.5	1.65
3 2 [illegible]	3-NULL 8TH-	SRB 2X4	SRB 1X3	TIT34D 2ND	CENT D1-T	60587.1	1.65
[illegible] 1 2	2-NULL 8TH-	SRB 2X5	SRB 1X2	CENT 48	IUS 2STAGE	60394.4	1.53
3 1 2	1-NULL 8TH-	SRB 2X5	SRB 1X2	CENT 48	TIT3 TRAN	60341.0	1.53

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Appendix A-4 Class B GEO Capability (Sheet 1)

CONFIG CODE	STRAP-ON	STAGE 1	STAGE 2	STAGE 3	STAGE 4	PAYLOAD	% PAYLOAD
3 3 1 3	4-NULL OTH-	SRB 2X5	SRB 1X2	TIT34D 2ND	CENT 48	15259.0	.36
3 3 1 5	4-NULL OTH-	SRB 2X5	SRB 1X2	S-1	CENT 48	15159.5	.34
3 2 4 5	4-NULL OTH-	SRB 2X4	SRB 1X5	SRB 1X1	CENT 48	15012.4	.33
3 3 2 5	4-NULL OTH-	SRB 2X5	SRB 1X3	S-1	CENT 48	14958.4	.35
3 2 4 5	4-NULL OTH-	SRB 2X4	SRB 1X5	S-1	CENT 48	14658.4	.35
3 3 2 3	4-NULL OTH-	SRB 2X5	SRB 1X3	TIT34D 2ND	CENT 48	14649.7	.35
3 2 4 3	4-NULL OTH-	SRB 2X4	SRB 1X5	TIT34D 2ND	CENT 48	14619.5	.34
3 3 1 5	4-NULL OTH-	SRB 2X5	SRB 1X2	SRB 1X1	CENT 48	14274.1	.33
3 2 3 5	4-NULL OTH-	SRB 2X4	SRB 1X4	S-1	CENT 48	14148.3	.35
3 2 3 5	4-NULL OTH-	SRB 2X4	SRB 1X4	SRB 1X1	CENT 48	14076.9	.33
3 2 3 3	4-NULL OTH-	SRB 2X4	SRB 1X4	TIT34D 2ND	CENT 48	13982.5	.35
3 2 1 3	4-NULL OTH-	SRB 2X4	SRB 1X2	TIT34D 2ND	CENT 48	13370.7	.4
3 3 1 3	4-NULL OTH-	SRB 2X5	SRB 1X2	TIT34D 2ND	CENT D1-T	13311.2	.34
3 2 1 5	4-NULL OTH-	SRB 2X4	SRB 1X2	S-1	CENT 48	13275.9	.39
3 2 2 5	4-NULL OTH-	SRB 2X4	SRB 1X3	S-1	CENT 48	131[illegible].5	.35
3 3 1 5	3-NULL OTH-	SRB 2X5	SRB 1X2	S-1	CENT D1-T	13[illegible]1.5	.33
3 1 4 5	4-NULL OTH-	SRB 2X3	SRB 1X5	SRB 1X1	CENT 48	13111.2	.33
3 2 2 3	4-NULL OTH-	SRB 2X4	SRB 1X3	TIT34D 2ND	CENT 48	13056.5	.35
3 2 2 5	4-NULL OTH-	SRB 2X4	SRB 1X3	SRB 1X1	CENT 48	12948.4	.33
3 1 4 5	4-NULL OTH-	SRB 2X3	SRB 1X5	S-1	CENT 48	12914.9	.35
3 3 2 5	3-NULL OTH-	SRB 2X5	SRB 1X3	S-1	CENT D1-T	12842.1	.3
3 3 2 3	3-NULL OTH-	SRB 2X5	SRB 1X3	TIT34D 2ND	CENT D1-T	12828.5	.3
3 1 4 3	4-NULL OTH-	SRB 2X3	SRB 1X5	TIT34D 2ND	CENT 48	12721.1	.35
3 2 4 5	3-NULL OTH-	SRB 2X4	SRB 1X5	S-1	CENT D1-T	12594.2	.3
3 2 4 3	3-NULL OTH-	SRB 2X4	SRB 1X5	TIT34D 2ND	CENT D1-T	12549.2	.3
3 2 1 5	4-NULL OTH-	SRB 2X4	SRB 1X2	SRB 1X1	CENT 48	12464.5	.34
3 3 1 4	4-NULL OTH-	SRB 2X5	SRB 1X2	S-2	CENT 48	12310.5	.31
3 1 3 5	4-NULL OTH-	SRB 2X3	SRB 1X4	S-1	CENT 48	12195.7	.35
3 1 3 5	4-NULL OTH-	SRB 2X3	SRB 1X4	SRB 1X1	CENT 48	12151.9	.35
3 2 3 5	3-NULL OTH-	SRB 2X4	SRB 1X4	S-1	CENT D1-T	12119.5	.3
3 2 3 3	3-NULL OTH-	SRB 2X4	SRB 1X4	TIT34D 2ND	CENT D1-T	12[illegible]16.5	.3
3 1 3 3	3-NULL OTH-	SRB 2X3	SRB 1X4	TIT34D 2ND	CENT 48	12039.2	.35
3 2 4 5	3-NULL OTH-	SRB 2X4	SRB 1X5	SRB 1X1	CENT D1-T	11954.3	.25
3 3 2 4	4-NULL OTH-	SRB 2X5	SRB 1X3	S-2	CENT 48	11727.5	.25
3 2 1 3	3-NULL OTH-	SRB 2X4	SRB 1X2	TIT34D 2ND	CENT D1-T	11581.5	.35
3 2 1 5	3-NULL OTH-	SRB 2X4	SRB 1X2	S-1	CENT D1-T	11493.4	.34
3 2 4 4	4-NULL OTH-	SRB 2X4	SRB 1X5	S-2	CENT 48	11395.1	.27
3 2 2 5	3-NULL OTH-	SRB 2X4	SRB 1X3	S-1	CENT D1-T	11304.2	.31
3 2 2 3	3-NULL OTH-	SRB 2X4	SRB 1X3	TIT34D 2ND	CENT D1-T	11295.7	.31
3 3 1 5	3-NULL OTH-	SRB 2X5	SRB 1X2	SRB 1X1	CENT D1-T	11244.3	.25
3 1 1 3	4-NULL OTH-	SRB 2X3	SRB 1X2	TIT34D 2ND	CENT 48	11248.5	.4
3 1 1 5	4-NULL OTH-	SRB 2X3	SRB 1X2	S-1	CENT 48	11242	.4
3 1 2 5	4-NULL OTH-	SRB 2X3	SRB 1X3	S-1	CENT 48	11230.1	.35
3 2 3 5	3-NULL OTH-	SRB 2X4	SRB 1X4	SRB 1X1	CENT D1-T	11182.5	.25
3 1 2 3	4-NULL OTH-	SRB 2X3	SRB 1X3	TIT34D 2ND	CENT 48	11151.6	.35
3 1 4 5	3-NULL OTH-	SRB 2X3	SRB 1X5	S-1	CENT D1-T	11053.7	.3
3 1 2 5	4-NULL OTH-	SRB 2X3	SRB 1X3	SRB 1X1	CENT 48	11041.9	.33
3 1 4 3	3-NULL OTH-	SRB 2X3	SRB 1X5	TIT34D 2ND	CENT D1-T	10933.2	.3
3 2 3 4	4-NULL OTH-	SRB 2X4	SRB 1X4	S-2	CENT 48	10989.6	.29
3 2 1 4	4-NULL OTH-	SRB 2X4	SRB 1X2	S-2	CENT 48	10664.7	.32
3 1 1 5	4-NULL OTH-	SRB 2X3	SRB 1X2	SRB 1X1	CENT 48	10582.3	.34
3 1 3 5	3-NULL OTH-	SRB 2X3	SRB 1X4	S-1	CENT D1-T	10456.3	.31
3 1 3 3	3-NULL OTH-	SRB 2X3	SRB 1X4	TIT34D 2ND	CENT D1-T	10391.5	.31
3 1 4 5	3-NULL OTH-	SRB 2X3	SRB 1X5	SRB 1X1	CENT D1-T	10397.3	.25
3 3 1 4	3-NULL OTH-	SRB 2X5	SRB 1X2	S-2	CENT D1-T	10243.4	.25
3 2 2 5	3-NULL OTH-	SRB 2X4	SRB 1X3	SRB 1X1	CENT D1-T	10193.9	.25
3 2 2 4	4-NULL OTH-	SRB 2X4	SRB 1X3	S-2	CENT 48	10179.5	.25
3 1 1 3	3-NULL OTH-	SRB 2X3	SRB 1X2	TIT34D 2ND	CENT D1-T	9887.19	.35
3 2 1 5	3-NULL OTH-	SRB 2X4	SRB 1X2	SRB 1X1	CENT D1-T	9886.19	.27
3 1 4 4	4-NULL OTH-	SRB 2X3	SRB 1X5	S-2	CENT 48	9755.81	.27

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Appendix A4 Class B GEO Capability (Sheet 2)

CONFIG CODE	STRAP-ON	STAGE 1	STAGE 2	STAGE 3	STAGE 4	PAYLOAD	% PAYLOAD
[illegible] 1 1 5	3-[illegible] [illegible]	S[illegible] 2X3	S[illegible] 1X2	S-1	CENT D1-T	[illegible]716.84	.3
[illegible] 1 2 3	3-[illegible] [illegible]	S[illegible] [illegible]X3	S[illegible] 1X3	S-1	CENT D1-T	[illegible]634.56	.3
[illegible] 1 2 [illegible]	3-[illegible] [illegible]	S[illegible] 2X3	S[illegible] 1X3	[illegible]	CENT D1-T	[illegible]627.31	.3
[illegible] 3 2 4	3-[illegible] [illegible]	S[illegible] 2X5	S[illegible] 1X3	S-2	CENT D1-T	96[illegible].[illegible]	.2
[illegible] 1 3 5	3-[illegible] [illegible]	S[illegible] 2X3	S[illegible] 1X[illegible]	S[illegible] 1X1	CENT D1-T	954[illegible].[illegible]	.2
[illegible] 1 3 [illegible]	[illegible]-[illegible] [illegible]	S[illegible] 2X3	S[illegible] 1X[illegible]	S-[illegible]	CENT [illegible]	9235.[illegible]1	.2
[illegible] 2 [illegible] [illegible]	3-[illegible] [illegible]	S[illegible] 2X[illegible]	S[illegible] 1X5	S-2	CENT D1-T	9233.15	.2

APPENDIX B—SUPPORTING WEIGHT DATA

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Appendix B-1 LEO Vehicle Weight Breakdown

WEIGHT REPORTING

PAYLOAD		60,700
PAYLOAD ADAPTER		800
STAGE 4 (D-IT)		———
PROPELLANT - INCL FPR	———	
INERTS *	———	
TRUSS ADAPTER	———	
SHROUD		9,510
NOSE CONE	2,000	
PAYLOAD SECTION	6,900	
STAGE 4 SECTION - LESS BASE	———	
BASE - ABOVE SEP JOINT	360	
BASE - BELOW SEP JOINT	250	
FORWARD BEARING REACTION SYSTEM		———
STAGE 4 RETAINED	———	
SHROUD RETAINED	———	
INTERSTAGE 3 - 4		———
CONTROL MODULE		2,200
AVIONICS/ELECT/STRUCT	1,800	
PROPULSION - RCS	400	
STAGE 3 (T2S)		109,300
PROPELLANT - INCL FPR	101,380	
INERTS **	7,920	
INTERSTAGE 2-3		1,500
STAGE 2 (2-SEG SRB)		684,030
PROPELLANT	605,140	
SRM INERTS - FW CASES	60,190	
SRB SUBSYSTEMS - INCL RCS	18,700	
INTERSTAGE 1 - 2		22,320
RING ASSEMBLY	2,320	
TITAN SECTION - LESS BASE	4,900	
BASE - ABOVE SEP JOINT	350	
BASE - BELOW SEP JOINT	250	
FWD STRUTS - STG 2 RETAINED	720	
FWD STRUTS - RING ASSY RETAINED	660	
FWD STRUTS - STG 1 RETAINED	360	
FWD STRUTS - JETTISONED	6,160	
AFT STRUTS - STG 2 RETAINED	1,480	
AFT STRUTS - STG 1 RETAINED	2,480	
AFT STRUTS - JETTISONED	2,640	
STAGE 1 (TWO 4-SEG SRB'S)		2,517,880
PROPELLANT	2,215,180	
SRM INERTS - FW CASES	223,700	
SRB SUBSYSTEMS	79,000	
(GROSS WEIGHT)		(3,408,240)

WEIGHTS FOR PERFORMANCE

PAYLOAD ADAPTER	61,500
STG 4 PROPELLANT	———
STG 4 INERTS	———
STG 3 PROPELLANT	101,380
STG 3 INERTS	10,120
STG 2 PROPELLANT	605,140
STG 2 INERTS	82,840
SHROUD	17,740
STG 1 PROPELLANT	2,215,180
STG 1 INERTS	314,340
(GROSS WEIGHT)	(3,408,240)

* AS ADJUSTED TO REFLECT REMOVAL OF STANDARD TRUSS ADAPTER (280 LB) AND RETAINED STANDARD FRB SYSTEM (30 LB)

** AS ADJUSTED TO REFLECT 35-INCH REDUCTION IN LENGTH OF FORWARD SKIRT (230 LB)

Appendix B-2 GEO Vehicle Weight Breakdown

WEIGHT REPORTING			WEIGHTS FOR PERFORMANCE	
PAYLOAD		12,100	PAYLOAD	12,100
PAYLOAD ADAPTER		200		
STAGE 4 (D-IIT)		35,100		
PROPELLANT - INCL FPR	30,000		STG 4 PROPELLANT	30,000
INERTS *	4,540		STG 4 INERTS	5,330
TRUSS ADAPTER	560			
SHROUD		11,880		
NOSE CONE	2,000			
PAYLOAD SECTION	4,830			
STAGE 4 SECTION - LESS BASE	4,440			
BASE - ABOVE SEP JOINT	360			
BASE - BELOW SEP JOINT	250			
FORWARD BEARING REACTION SYSTEM		500		
STAGE 4 RETAINED	30			
SHROUD RETAINED	470			
INTERSTAGE 3 - 4		900		
CONTROL MODULE		1700		
AVIONICS/ELECT/STRUCT	1,300			
PROPULSION - RCS	400			
STAGE 3 (T2S)		109,300		
PROPELLANT - INCL FPR	101,380		STG 3 PROPELLANT	101,380
INERTS **	7,920		STG 3 INERTS	10,520
INTERSTAGE 2 - 3		1,500		
STAGE 2 (2-SEG SRB)		684,030		
PROPELLANT	605,140		STG 2 PROPELLANT	605,140
SRM INERTS - FW CASES	60,190		STG 2 INERTS	82,840
SRB SUBSYSTEMS - INCL RCS	18,700			
INTERSTAGE 1 - 2		22,320		
RING ASSEMBLY	2,320			
TITAN SECTION - LESS BASE	4,900			
BASE - ABOVE SEP JOINT	350			
BASE - BELOW SEP JOINT	250			
FWD STRUTS - STG 2 RETAINED	720		SHROUD	20,580
FWD STRUTS - RING ASSY RETAINED	660			
FWD STRUTS - STG 1 RETAINED	360			
FWD STRUTS - JETTISONED	6,160			
AFT STRUTS - STG 2 RETAINED	1,480			
AFT STRUTS - STG 1 RETAINED	2,480			
AFT STRUTS - JETTISONED	2,640			
STAGE 1 (TWO 4-SEG SRB'S)		2,517,880		
PROPELLANT	2,215,180		STG 1 PROPELLANT	2,215,180
SRM INERTS - FW CASES	223,700		STG 1 INERTS	314,340
SRB SUBSYSTEMS	79,000			
(GROSS WEIGHT)		(3,397,410)	(GROSS WEIGHT)	(3,397,410)

* AS ADJUSTED TO REFLECT REMOVAL OF STANDARD TRUSS ADAPTER (280 LB) AND RETAINED STANDARD FRB SYSTEM (30 LB)

** AS ADJUSTED TO REFLECT 35-INCH REDUCTION IN LENGTH OF FORWARD SKIRT (230 LB)

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Appendix B-3 SRB Subsystems Weight Breakdown (Sheet 1)

GROUP/ITEM	STS [1] STG 1 4-SEG WEIGHT	STS [1] STG 1 4-SEG XCG AFT OF NOSE	SRB-X STG 1 4-SEG WEIGHT	SRB-X STG 1 4-SEG XCG AFT OF NOSE	SRB-X STG 2 2-SEG WEIGHT	SRB-X STG 2 2-SEG XCG AFT OF NOSE
BODY STRUCTURE	(25,925)		(25,672)		(13,480)	
NOSE CAP	275		275		—	
FRUSTRUM	3,801		3,801		—	
SEPARATION RING	156		156		—	
FORWARD SKIRT	6,412		6,256		7,800	
BASIC SKIRT	5,164		5,164		5,116	
THRUST POST AND FITTING	1,092		1,092		2,184	
SRB/ET ATTACH HDW [2]	156		—		—	
EXTERNAL FITTINGS	—		—		500	
AFT ATTACH RING	952		1,400		1,800	
SRB/ET ATTACH STRUTS [2]	545		—		—	
AFT SKIRT	13,038		13,038		3,300	
BASIC SKIRT	10,136		10,136		3,000	
HOLDDOWN STRUCTURE	2,705		2,705		200	
SEPARATION MOTOR MOUNTS	197		197		100	
SYSTEMS TUNNEL	746		746		580	
FORWARD SKIRT	45		45		45	
MOTOR CASE	400		400		250	
AFT ATTACH RING	175		175		175	
AFT SKIRT	60		60		60	
SPLICES/ASSEMBLY	66		66		50	
INDUCED ENVIRON PROTECTION	(1,767)		(1,723)		(782)	
THERMAL PROTECTION	1,598		1,554		682	
NOSE CONE	27		27		—	
FRUSTRUM	81		81		—	
SEPARATION RING	8		8		—	

[1] MASS PROPERTIES REPORT NO. 64 (3/26/82)
[2] SRB SIDE OF SEPARATION PLANE

Appendix B-3 SRB Subsystems Weight Breakdown (Sheet 2)

GROUP/ITEM	STS [1] STG 1 4-SEG WEIGHT	STS [1] STG 1 4-SEG XCG AFT OF NOSE	SRB-X STG 1 4-SEG WEIGHT	SRB-X STG 1 4-SEG XCG AFT OF NOSE	SRB-X STG 2 2-SEG WEIGHT	SRB-X STG 2 2-SEG XCG AFT OF NOSE
INDUCED ENVIRONMENTAL PROTECTION (CONTINUED)						
THERMAL PROTECTION (CONTINUED)						
FORWARD SKIRT/ATT HDW	88		70		——	
AFT ATTACH RING/STRUTS	344		318		50	
AFT SKIRT	518		518		100	
HEAT SHIELD	532		532		532	
PAINT	146		146		100	
SEALANT	23		23		——	
SEPARATION	(1,343)		(1,343)		(349)	
FORWARD MOTORS - INCL PROP	653		653		——	
AFT MOTORS - INCL PROP	654		654		327	
CDF/MANIFOLD ASSY	30		30		20	
INSTALLATION HARDWARE	6		6		2	
RECOVERY	(7,333)		(7,333)		(——)	
THRUST VECTOR CONTROL	(2,329)		(2,329)		(2,329)	
ELECTRICAL & INSTRUMENTATION	(1,026)		(1,018)		(678)	
BATTERY	45		45		45	
RECOVERY AIDS	3		3		——	
BARO SWITCH	32		32		——	
TRANSDUCERS	13		13		13	
WIRE - INCL STRUT HARNESS	521		513		395	
INTEGRATED ELECTRONIC ASSYS	374		374		187	
BRACKETS & SUPPORTS	10		10		10	
RATE GYROS	28		28		28	
RANGE SAFETY & ABORT	(150)		(150)		(150)	
ROUNDOUT/ADJUSTMENTS	(+ 2)		(– 68) *		(– 68) *	
TOTAL	39,875		39,500		17,700	

[1] MASS PROPERTIES REPORT NO. 64 (3/26/82)

*OVERLOOKED + 68 LB INCREASE IN TVC FIRST TIME AROUND

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Appendix B-4 FWC Four-Segment SRM Weights

	WEIGHT (LBM)
FORWARD SEGMENT	323,432
FORWARD DOME	3,669
COMPOSITE	10,097
FORWARD ATTACH RING	1,060
AFT ATTACH RING	1,200
PINS	437
INSULATION-LINER-INHIBITOR	4,520
IGNITER	461
SYSTEMS TUNNEL	118
EXTERNAL INSULATION	190
PROPELLANT	301,543
IGNITER PROPELLANT	137
FORWARD CENTER SEGMENT	288,346
COMPOSITE	9,969
FORWARD ATTACH RING	1,060
AFT ATTACH RING	1,200
PINS	366
INSULATION-LINER-INHIBITOR	3,494
SYSTEMS TUNNEL	110
EXTERNAL INSULATION	190
PROPELLANT	271,957
AFT CENTER SEGMENT	288,478
COMPOSITE	9,969
FORWARD ATTACH RING	1,060
AFT ATTACH RING	1,200
PINS	366
INSULATION-LINER-INHIBITOR	3,494
SYSTEMS TUNNEL	110
EXTERNAL INSULATION	322
PROPELLANT	271,957
AFT SEGMENT	295,677
AFT DOME	4,965
ATTACH SEGMENT	6,590
COMPOSITE	7,912
FORWARD ATTACH RING	1,060
AFT ATTACH RING	1,200
PINS	508
INSULATION-LINER-INHIBITOR	10,981
SYSTEMS TUNNEL	154
EXTERNAL INSULATION	312
PROPELLANT	261,995
FIELD JOINTS	204
NOZZLE	23,304
TOTAL INERTS	111,852
TOTAL PROPELLANT	1,107,589
TOTAL MOTOR	1,219,441

Appendix B-5 SRB-X FWC Two-Segment SRM Weights

FORWARD SEGMENT	20,937
FORWARD DOME	3,669
COMPOSITE	10,097
FORWARD ATTACH RING	1,060
AFT ATTACH RING	1,200
PINS	437
INSULATION-LINER	4,166
SYSTEMS TUNNEL	118
EXTERNAL INSULATION	190
AFT SEGMENT	25,656
AFT DOME	4,965
ATTACH SEGMENT	6,590
COMPOSITE	7,912
FORWARD ATTACH RING	1,060
AFT ATTACH RING	1,200
PINS	508
INSULATION-LINER	2,955
SYSTEMS TUNNEL	154
EXTERNAL INSULATION	312
NOZZLE	13,284
IGNITER	240
FIELD JOINT	72
TOTAL MOTOR INERTS	60,189
PROPELLANT	605,136
TOTAL MOTOR	665,325

Appendix B-6 Control Module Weights

	LEO		GEO	
STRUCTURE		400		400
THERMAL CONTROL		20		20
AVIONICS		590		360
COMMUNICATION	73		73	
DATA MANAGEMENT	315		132	
FLIGHT CONT	120		120	
INSTRUMENTATION	82		35	
ELECTRICAL		620		440
POWER SOURCE	210		30	
POWER DISTRIBUTION	410		410	
PROPULSION		380		380
TANKS, THRUSTERS	180		180	
PROPELLANT	200		200	
MARGIN		190		100
TOTAL		2,200		1,700